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bodies to colonise
the cosmos

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DREAMS
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FORGET**

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The **deeper** a sea creature lives, the **smellier** it is → p82

WELCOME



"Space is disease and danger wrapped in darkness and silence." This line delivered by Bones in 2009's *Star Trek* pretty much sums up space travel for me. I *think* I'd like to go to space, but I find flying in our own atmosphere taxing enough. And every time I meet someone from NASA or ESA they remind me, with one small but gory detail, how terrible spaceflight can be.

For example, you can't burp in space. I'm not saying I'd miss it, but your bodily fluids, unshackled from the bondage of gravity, will make a bid for freedom if they're given the chance. Similarly, in the weightless world of the ISS, your body seems to decide you need less skeleton, so you expel calcium and minerals in your urine, which in turn clogs up the space toilet.

The list goes on. Millions of years of evolution has made our biology pretty good at life on Earth, but less good at life in the cosmos. This issue is at the forefront of NASA's and ESA's thinking right now. If they want to send people to stay on the Moon and Mars for longer periods they'll have to be able to survive the trip. Turn to p38 to discover the ways scientists are solving these challenges.

Daniel Bennett

Daniel Bennett, Editor

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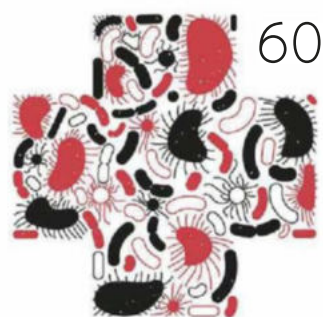
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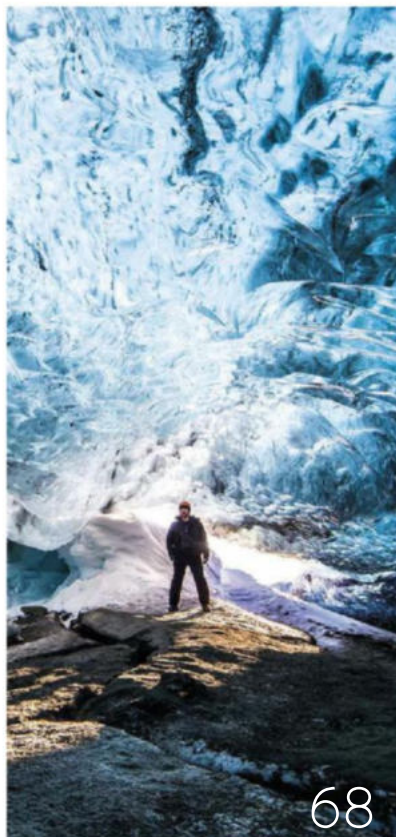
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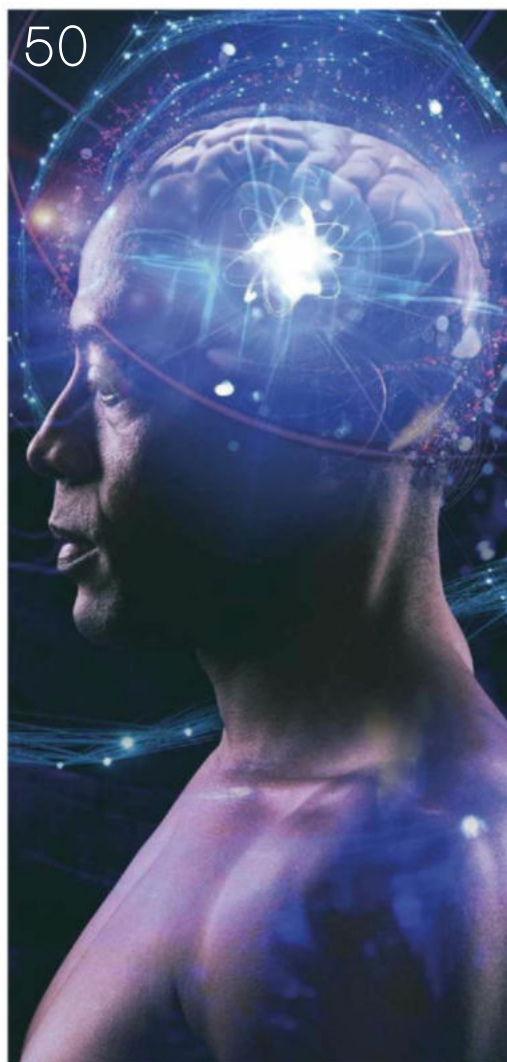
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EYE OPENER

Natural born killer

LEMBEH,
INDONESIA

This blue and white harlequin shrimp was snapped by photographer Aldo Costa, who spotted it while diving in the waters off Lembeh, Indonesia.

The little crustaceans can grow to about five centimetres in length, and they live together as couples, with one male and one female. However, their beautiful appearance belies predatory habits that would make Bonnie and Clyde blush. The pair of shrimp go hunting for starfish, their main food source. Once they've found one, they'll work together to overpower it and flip it on its back. They'll then start consuming its tube feet, which are structures that the starfish uses for locomotion. Sometimes, they carry the unfortunate animal back to their lair, to continue eating it alive over a period of days or weeks. Incredibly, the shrimp have been recorded bringing food to the starfish, to keep it alive for even longer.

The starfish underneath the shrimp in this image had better make its escape – quickly!

PHOTO: ALDO COSTA









EYE OPENER

Divided desert

MINQIN COUNTY, GANSU PROVINCE
CHINA

In Minqin County, northwest China, farmers build grid-like structures from hay to stabilise sand dunes in an attempt to prevent the desert encroaching onto their land. It's part of an initiative by the local government, which announced that it would spend six years building a 1km-wide green barrier, measuring 500km in length.

Minqin County is located between two deserts: Tengger and Badain Jaran. The area was historically an oasis, with a lake that was fed by water from the Shiyang river. But in the 1950s, the government diverted the water to boost food production elsewhere. Since then, residents have had to rely on groundwater sources, but these have also become overexploited. The lack of groundwater, combined with low rainfall, means that much of the scarce water is undrinkable.

While the government previously tried to assist by planting vegetation and forests, its attempts failed and thousands of people were forced to leave the area.

PHOTO: EYEVINE

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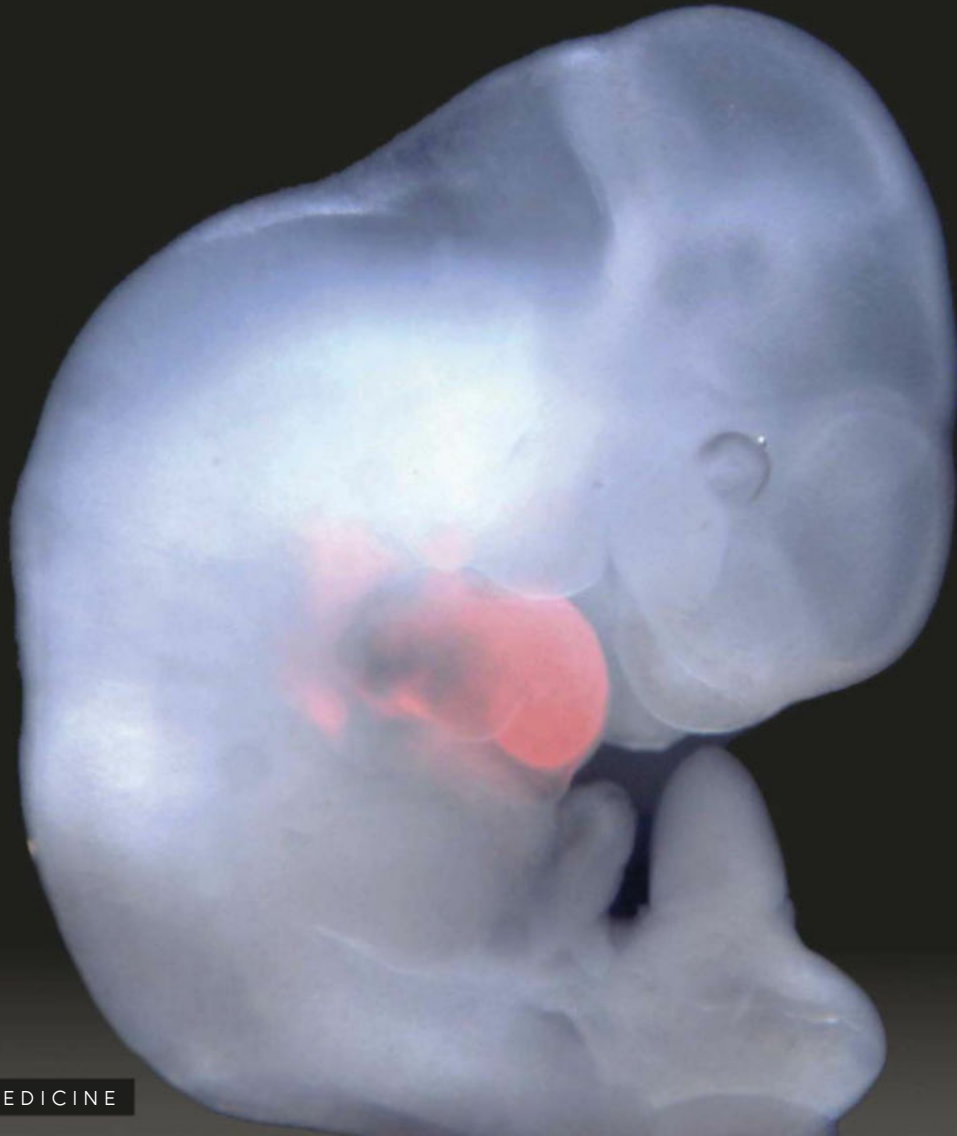
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DISCOVERIES

DISPATCHES FROM THE CUTTING EDGE

MARCH 2017

EDITED BY JASON GOODYER



MEDICINE

HUMAN-PIG 'CHIMERA' EMBRYOS GROWN IN THE LAB FOR THE FIRST TIME

The technique represents an important step towards growing human organs for transplant, say researchers

PHOTO: JUAN CARLOS IZPISUA BELMONTE

“WE STILL
HAVE MUCH TO
LEARN ABOUT
THE EARLY
DEVELOPMENT
OF CELLS”



A team at the Salk Institute has grown the first living embryos containing cells from both human beings and pigs.

To create the human-pig chimeras, the researchers injected human stem cells – master cells that can develop into any type of tissue – into pig embryos. The stem cells survived and began to integrate with the pig tissue to form a chimeric human-pig embryo. These embryos were implanted in sows and allowed to develop for up to four weeks.

“This is long enough for us to try to understand how the human and pig cells mix together early on, without raising ethical concerns about mature chimeric animals,” said lead investigator Juan Carlos Izpisua Belmonte.

However, the process is currently very inefficient – out of the 2,075 embryos created, just 186 stayed alive for the full four weeks.

“It’s like when you try to duplicate a key. The duplicate looks almost identical, but when you get home, it doesn’t open the door. There is something we are not doing right,” said Izpisua Belmonte. “We thought growing human cells in an animal would be much more fruitful. We still have much to learn about the early development of cells.”

Though they sound disturbing, human-animal chimeras may someday provide a means of growing human tissues and organs for transplant – potentially saving thousands of lives.

“The ultimate goal is to grow functional and transplantable tissue or organs, but we are far away from that,” said Izpisua Belmonte. “This is an important first step.”

The next step is to guide the stem cells into forming specific human organs within the pigs. The

ABOVE: The work of the Salk Institute team, led by Juan Carlos Izpisua Belmonte, could pave the way for lab-grown transplant organs

Prof Robin Lovell-Badge

Group leader, The Francis Crick Institute

“An ability to make interspecies chimeras would be valuable in terms of providing basic understanding of species differences in embryo development and organ function. If human cells are incorporated, then this offers the possibility of using such chimeras to study not just normal development, but the causes of congenital defects; to test the effects of exogenous [outside the body] agents on human development, from chemicals to viruses such as Zika; and to test potential therapies. It would also offer the possibility of growing human tissues or organs in animals for transplants – although this is still a long way off. The goals of this study are therefore highly laudable.

“There is currently much interest in these kinds of approaches, particularly with respect to animals containing human cells or tissues, and how far these should go. Experiments involving chimeras, whether they are animal to animal or animals containing human material, are subject to regulation in the UK via the Home Office. The authors of this study, who are based in the USA, have been careful to follow guidelines issued by the International Society for Stem Cell Research (ISSCR), which match well with the UK regulations.”

team has previously used CRISPR genome editing tools to delete specific genes involved with organ development in fertilised mouse egg cells and replace them with rat stem cells. As the organism matured, the rat cells filled in where mouse cells could not, forming the functional tissues of the organism’s heart, eye or pancreas.

The researchers are now working on reproducing this effect in the human-pig embryos.

ASTRONOMY

LONGEST-EVER BLACK HOLE FEEDING FRENZY RECORDED

Now this really is a long lunch: a team at the University of New Hampshire has found a giant black hole that has been chowing down on a nearby star for almost a decade. That's over 10 times longer than any other instance of star death previously recorded.

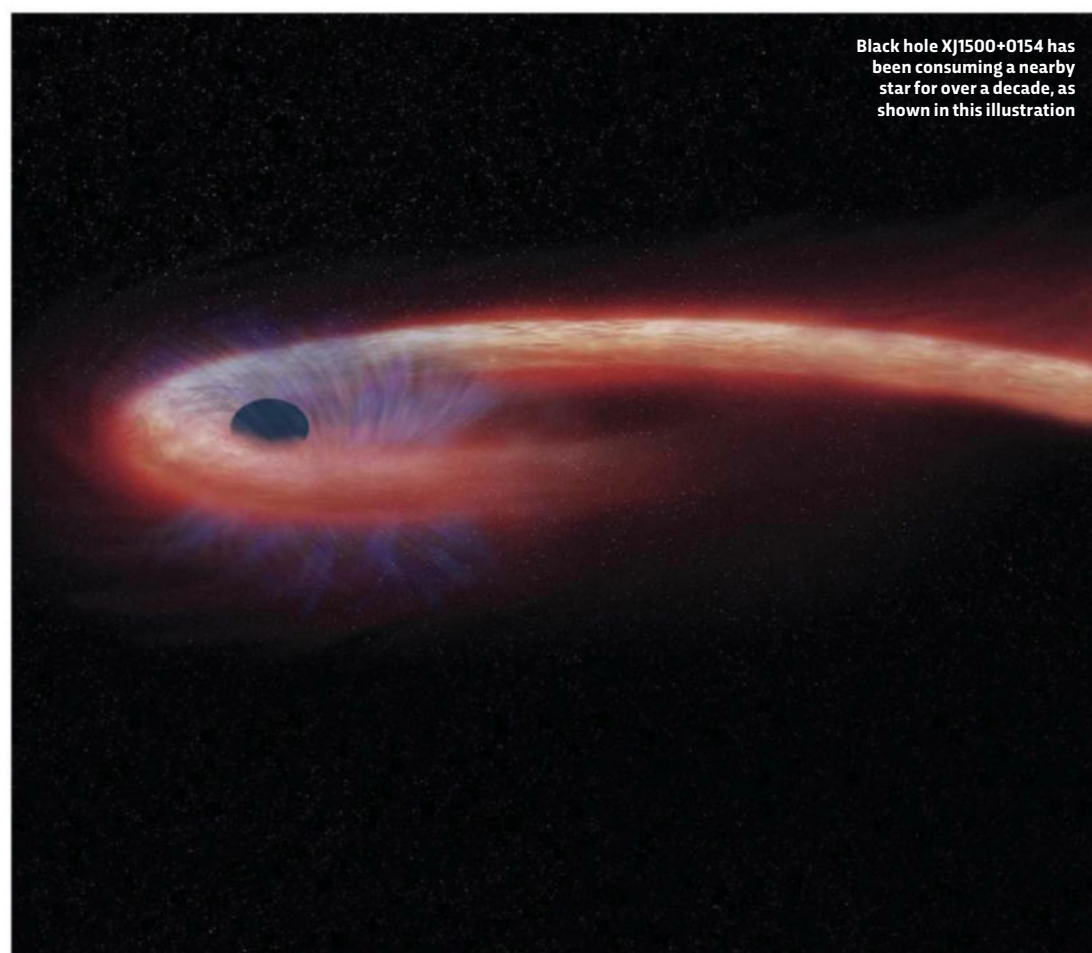
Dubbed XJ1500+0154, the black hole is located in a small galaxy about 1.8 billion light-years from Earth. Its epic meal is an example of a tidal disruption event (TDE), a phenomenon that occurs when an object such as a star wanders too close to a black hole, and is captured in its powerful gravitational field.

During a TDE, some of the material making up the star is flung outward at high speeds, while

the rest falls toward the black hole. As it travels inward it is ingested, heating up to millions of degrees and generating distinctive X-ray flares. It was these flares that were picked up by NASA's Chandra X-ray Observatory and Swift Satellite, and ESA's XMM-Newton, revealing the TDE.

"We have witnessed a star's spectacular and prolonged demise," said lead researcher Dacheng Lin. "Dozens of these so-called tidal disruption events have been detected since the 1990s, but none that remained bright for nearly as long as this one."

The black hole will continue to ingest the star for several more years, but at a reduced rate, say the researchers.



Black hole XJ1500+0154 has been consuming a nearby star for over a decade, as shown in this illustration

IN NUMBERS

90-ish

The age of Granddad, a lungfish kept at the Shedd Aquarium in Chicago who was euthanised after falling ill this month. He was the oldest fish kept in captivity.

6 DAYS

The length of time Canadian Melissa Benoit, a double lung transplant patient, was kept alive without lungs.

31.6g

The average amount of sugar in a single serving of branded soft drinks – 1.6g more than the recommended maximum daily intake.



ASTRONOMY

NASA TO EXPLORE METAL ASTEROID FOR THE FIRST TIME

Consider us psyched. NASA will be sending a probe to a distant metal asteroid for the first time ever. The mission was selected from five finalists as part of NASA's Discovery Program.

Scheduled to launch in 2023, the Arizona State University spacecraft will journey to 16 Psyche. This giant hunk of iron and nickel, locked in orbit about 280 million miles from the Sun, is thought to be the exposed metal core of a protoplanet. After reaching 16 Psyche in 2030, the probe will orbit the asteroid for 20 months, studying its properties with the aim of

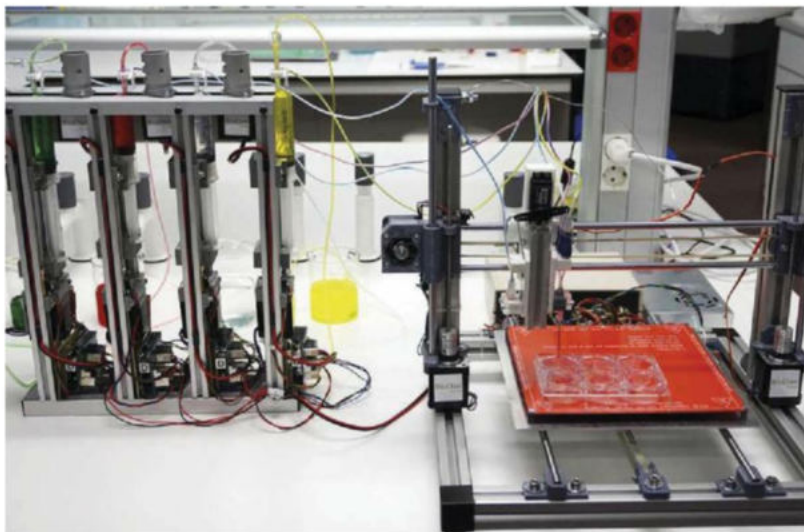
understanding more about how planets form. The team seeks to determine whether Psyche is in fact a protoplanetary core, how old it is, whether it formed in similar ways to Earth's core, and what its surface looks like.

"This mission will be the first time humans will ever be able to see a planetary core," said principal investigator Lindy Elkins-Tanton. "Having the Psyche mission selected for NASA's Discovery Program will help us gain insights into the metal interior of all rocky planets in our Solar System, including Earth."

16 Psyche is one of the 10 most massive bodies in the asteroid belt

BIOTECHNOLOGY

FUNCTIONING HUMAN SKIN PRINTED



The phrase 'gimme some skin' just took on a whole new meaning: a team from Madrid has used 3D printing technology to produce fully functioning human skin.

The printed skin replicates the natural structure of human skin. It includes an epidermis – an outer layer that acts as protection against the external environment – together with a thicker, deeper layer called the dermis. This layer is responsible for producing collagen, the protein that gives our skin its elasticity and strength.

The skin is produced from specially blended bio-inks created from human plasma and other cells. Computer-controlled injectors deposit these bio-inks onto a print bed, layer-by-layer.

"Knowing how to mix the biological components, in what conditions to work with them so that the cells don't deteriorate, and how to correctly deposit the product, is critical to the system," said researcher Juan Francisco del Cañizo, from the Hospital General Universitario Gregorio Marañón.

The skin can be produced using either stock cells, for use in pharmaceutical and cosmetic testing, or from the patient's own cells for therapeutic use, such as in the treatment of severe burns or other skin problems.

"The skin can be transplanted to patients or used in business settings to test chemical products, cosmetics or pharmaceutical products," said researcher José Luis Jorcano.

The breakthrough could help pave the way for the 3D printing of other artificial organs, the researchers say.

Human skin can now be 3D printed using special 'bio-inks'

PHOTOS: PETER RUBIN/ASU GETTY

THE DOWNLOAD

Misophonia

What's that? A symphony dedicated to tasty Japanese soup?

Not even close. It's the name of a condition that causes some people to find certain sounds, such as noisy eating or heavy breathing, unbearable.

Well, I can't say I'm particularly fond of slurpers or mouth-breathers myself...

That may be the case, but misophones suffer from extreme 'fight or flight' reactions when they hear certain trigger sounds, meaning that the condition can have a serious negative impact on their lives.

That sounds terrible. Do we know why it happens?

Until recently, many researchers were sceptical as to whether the condition even existed. Now, researchers at Newcastle University have found that misophones have an overactive anterior insular cortex, an area of the brain that links up senses and emotions.

So have we found a cure?

I'm afraid not. One idea is to pass low levels of electricity through the skulls of sufferers – a procedure that is known to adjust brain function.



BIOCHEMISTRY

"We can use man-made components and integrate them into the machinery of life"

Chemists have added synthetic letters to bacterial DNA. Study leader Prof Floyd Romesberg explains how this could expand the genetic code to make proteins never before seen in nature

What is the genetic alphabet?

All information that encodes the diversity of life is stored in DNA. The genetic alphabet has four letters [known as 'bases'] – G, C, A and T – and a critical property of that alphabet is that it forms base pairs [the rungs of the ladder in the DNA double-helix]. So G always pairs with C, and A always pairs with T. The four letters are what encode the information. You can translate the code into proteins, which perform all the functions of a cell.

How are your two synthetic letters different from natural ones?

Natural bases are hydrophilic, which means they're soluble in water. Our synthetic bases are hydrophobic, so they are insoluble in water. Our bases are oil-like, so they don't pair with the natural ones because oil doesn't like to mix with water. Let's call our bases X and Y. If X and Y pair with each other, it would give us six letters in total.

After adding synthetic letters to DNA in a test tube, and inserting them in bacteria, you've now managed to get the microbes to keep your 'unnatural base pairs'. Could any cell use synthetic bases?

We think so. We've shown there's nothing magic about a natural base pair, and that chemists can use any force available in nature – in this case, the fact that water and oil don't mix – to underlie the same type of thing in any organism. This is one of the things my lab is working on right now, specifically we're working with human cells.

Can cells read and decode DNA with synthetic bases?

That's what scientists call transcription of DNA into RNA, and translation of the RNA into proteins. Yes, it works. Part of the point of doing all this was just to demonstrate that we could. A lot of



RIGHT: Prof Floyd Romesberg (right) and graduate student Yorke Zhang (left) from the Scripps Research Institute led the study

PHOTOS: GETTY, MADELINE MCCURRY-SCHMIDT ILLUSTRATION: DANIEL BRIGHT



ABOVE: All life is coded in four 'letters', A, G, T and C, which pair up to form the 'rungs' on DNA's structure

people think the molecules that make life are different from those that are part of things that are not living. We've shown that's really not true. We can use synthetic components and integrate them into the machinery of life just fine.

How could synthetic letters be useful?

Traditionally, drugs have been small molecules, but in the last 20 years there's been growing success with proteins. But proteins are composed of only 20 little amino acid building blocks and a lot of them are pretty boring. There are certain types of functional groups of atoms that medicinal chemists have had success with in small molecules, but they aren't present in proteins. So we could develop proteins that have unnatural functionalities to make better drugs. That's the short-term goal.

Now the second, long-term application: instead of getting bacteria or human cells to make a protein to use elsewhere, couldn't we make the cell create proteins it uses for itself? So we could evolve bacteria that use unnatural proteins to do new things. Maybe they eat oil to help clean up spills, or maybe we could develop bacteria that you inject into a person and they localise to certain tissues, then secrete a drug. The potential applications are only limited by your imagination.



THE FOUL-MOUTHED

Those prone to a bit of effing and blinding are more honest than the rest of us, a team at the University of Cambridge has found. Just as they aren't filtering their language to be more palatable, they're also not filtering their views, the researchers say.

INSOMNIACS

Often find yourself bleary-eyed? Try heading to the great outdoors. Researchers in the US have found that a few days' camping can reset our internal clocks and help us sleep more soundly.

GOOD MONTH

BAD MONTH

DESK JOCKEYS

Sitting for more than 10 hours a day can take eight years off your life, a team at the University of California has found. They think that inactivity shortens the telomeres, which are caps that exist on the end of DNA and help stop cells ageing.

BIRDWATCHERS

This'll get twitchers' binocular straps in a twist: climate change could be making birds less attractive, Swedish researchers say. Though the exact mechanism is still unknown, hotter conditions seem to be letting plainer birds outcompete more ornamented counterparts.





MARS

MARS MAY BE HOME TO SOME OF THE OLDEST VOLCANOES IN THE SOLAR SYSTEM

This rocks. A team from the University of Houston has found a two-billion-year-old volcanic Martian meteorite, suggesting that some of the longest lived volcanoes in the Solar System are found on Mars.

Dubbed Northwest Africa 7635, the meteorite was discovered in Algeria in 2012 and is made from a type of volcanic rock known as shergottite. It made its way to Earth around one million years ago after a large object slammed into the surface of the Red Planet, hitting a volcano or lava plain. The impact sent a large volume of rocks careering into space, some of which entered Earth's orbit and fell as meteorites. In total, researchers have found 11 of these Martian meteorites, all with a similar chemical composition.

"We see that they came from a similar volcanic source," said lead researcher Tom

"THE LARGEST
MARTIAN
VOLCANO,
OLYMPUS
MONS, IS
NEARLY
22KM HIGH"

Lapen. "Given that they also have the same ejection time, we can conclude that these come from the same location on Mars."

Previously analysed Martian meteorites have ranged in age from 327 million to 600 million years old. But research has shown that Northwest Africa 7635 was formed 2.4 billion years ago, suggesting that it was ejected from one of the longest-lived volcanic centres in the Solar System.

Much of what is known about the composition of rocks from volcanoes on Mars comes from meteorites found on Earth. The shield-shaped volcanoes found on Mars are caused by lava flowing over long distances, similar to the formation of the Hawaiian Islands. The largest Martian volcano, Olympus Mons, is nearly 22km high – almost triple the height of Earth's tallest volcano, Mauna Kea.

PHOTOS: UNIVERSITY OF HOUSTON, SCIENCE PHOTO LIBRARY X2

MEDICINE

ANTIBIOTICS COULD KILL BACTERIA WITH BRUTE FORCE

Sometimes violence *is* the answer: a team at UCL has found that some antibiotics are capable of killing off drug-resistant bacteria if they ‘push’ hard enough into their cell structure. The discovery opens up a promising new way of overcoming antibiotic resistance and could lead to the design of even more effective drugs.

“Antibiotics work in different ways, but they all need to bind to bacterial cells in order to kill them. Antibiotics have ‘keys’ that fit ‘locks’ on bacterial cell surfaces, allowing them to latch on. When a bacterium becomes resistant to a drug, it effectively changes the locks so the key won’t fit any more,” said lead researcher Dr Joseph Ndieyira.

“Incredibly, we found that certain antibiotics can still ‘force’ the lock, allowing them to bind to and kill resistant bacteria because they are able to push hard enough. In fact, some of them were so strong they tore the door

off its hinges, killing the bacteria instantly!” he added.

The researchers found that although the two antibiotics oritavancin and vancomycin contain the same ‘key’ and exert the same force on susceptible bacteria, the former was able to kill drug-resistant bacteria by pressing itself into their cell structures with 11,000 times the force of the latter – effectively ripping them apart.

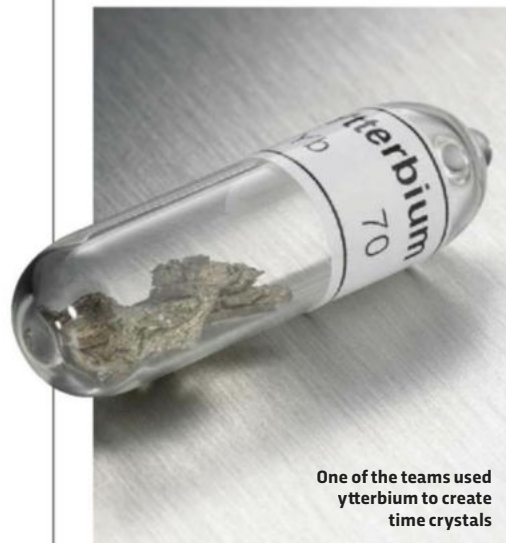
The team is now working on a mathematical model that could be used to screen promising new antibiotics, identifying the drugs that can kill bacteria by using brute force.

“Our findings will help us not only to design new antibiotics but also to modify existing ones to overcome resistance,” said Ndieyira. “This will help us to create a new generation of antibiotics to tackle multi-drug resistant bacterial infections, now recognised as one of the greatest global threats in modern healthcare.”



This image shows bubbly formations on *E. coli* bacteria caused by the action of antibiotics

PHYSICS



One of the teams used ytterbium to create time crystals

NEW FORM OF MATTER CREATED

Researchers in the US have created time crystals – substances with a structure that repeats in time.

Time crystals were first proposed in 2012 by Nobel laureate Frank Wilczek and feature a structure that repeats in a regular periodic motion in a manner compared to tapping jelly repeatedly in order to make it jiggle.

Now, based on the earlier work of the University of California’s Norman Yao, two separate teams of researchers have produced physical time crystals – one at the University of Maryland that involved hitting a line of ytterbium atoms with a pair of lasers, and another at Harvard University by exploiting tiny defects in diamonds.

“This is a new phase of matter, period, but it is also really cool because it is one of the first examples of non-equilibrium matter,” Yao said. “For the last half-century, we have been exploring equilibrium matter, like metals and insulators. We are just now starting to explore a whole new landscape of non-equilibrium matter.”

Though the applications of time crystals are as yet unclear, they could potentially be useful in the construction of quantum computers.

SPACESUITS GET STYLISH

When astronauts head to the International Space Station in Boeing's CST-100 Starliner capsule next year, it looks like they will do so in some style: the company has designed new spacesuits to provide crew members with improved functionality, comfort and protection – and they also look pretty snazzy.

Dubbed the 'Boeing Blue', the suits are around 40 per cent lighter than previous examples and feature a wide polycarbonate visor for improved peripheral vision, a built-in communications headset and touchscreen-friendly gloves. To improve comfort, the hood-like helmet simply zips on, overcoming the need for the cumbersome metal neck ring seen on previous designs.

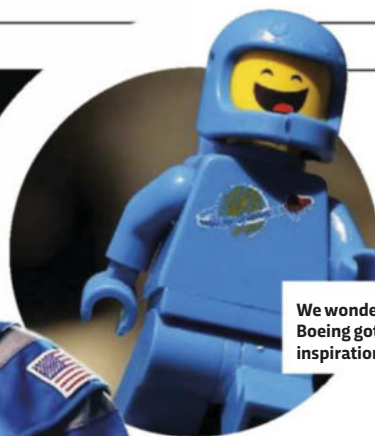
"It feels good to be walking around in Boeing Blue," said Chris Ferguson, director of Starliner crew and mission systems at Boeing. "Spacesuits have come in different sizes, shapes and designs, and I think this fits the Boeing model, fits the Boeing vehicle."

NASA awarded contracts to Boeing and SpaceX in 2014 to develop commercial spaceships that could be used to ferry astronauts to and from the ISS. Boeing plans to carry out an unpiloted test flight of a CST-100 in Earth orbit in June next year. If successful, Boeing will then send a test pilot and a NASA astronaut for an orbital test flight in August.

FROM LEFT TO RIGHT: NASA's Project Mercury spacesuit; Russia's Strizh spacesuit; Shannon Lucid's training suit; the 'Boeing Blue'



PHOTO: SHUTTERSTOCK X3; BOEING; ALAMY ILLUSTRATION: RAJA LOCKEY



We wonder where Boeing got its inspiration from...?

THEY DID WHAT?!

MOTHS TAUGHT TO DRIVE CARS

What did they do?

A team from Tokyo University got male silkmoths to drive robotic cars towards the source of sex pheromones produced by a female. The moths were tethered to a treadmill linked to optical sensors that tracked their movements and steered the vehicle.

Why did they do that?

The scientists hope that the research will eventually lead to the development of biomimetic robots that can sniff out odours and locate their sources. Such robots could replace dogs and other animals used for detecting explosives or drugs.

What did they find?

The moth drivers passed the test with flying colours, taking just two seconds longer than free-walking moths in finding the source of the scent. Though like most of us, they picked up a few minor faults.



It's like looking in a mirror...



EVOLUTION

MEET YOUR MANY TIMES GREAT GRANDDAD: A BAG-LIKE CREATURE WITHOUT AN ANUS

It may not look much like Auntie Jean or Uncle Bob, but this tiny sea creature could be your oldest known ancestor.

Dubbed *Saccorhytus*, thanks to its oval, sack-like body and large mouth, the newly discovered species lived nestled in the sand on the seabed of central China 540 million years ago. It was found lodged inside microfossils unearthed by a team from the University of Cambridge and is thought to be the most primitive example of a deuterostome – one of the major groups of the animal kingdom that includes several smaller groups, including vertebrates.

“We think that as an early deuterostome this may represent the primitive beginnings of a very diverse range of species, including ourselves,” said researcher Prof Simon Conway Morris. “To the naked eye, the fossils we studied look like tiny black

grains, but under the microscope the level of detail is jaw-dropping. All deuterostomes had a common ancestor, and we think that is what we are looking at here.”

By isolating the fossils from the surrounding rock, and then studying them under an electron microscope and a CT scanner, the team were able to build up a picture of how *Saccorhytus* might have looked and lived. It was covered in a thin, flexible skin suggesting that it had some kind of musculature and could have got around by wriggling. Intriguingly, the researchers were unable to find any evidence that the creature had an anus.

“If that was the case, then any waste material would simply have been taken out back through the mouth, which from our perspective sounds rather unappealing,” Conway Morris said.

WHAT WE LEARNED THIS MONTH

DOGS ARE FANS OF SOFT ROCK

If you find your pooch is getting a bit stressed, put on some Billy Joel. A team at the University of Glasgow has found soft rock music can have a calming effect on pent-up pups.

BLACK HUMOUR IS A SIGN OF INTELLIGENCE

If you want to know how smart someone is, tell them a sick joke. Those with a particularly dark sense of humour score more highly in IQ tests, researchers at the University of Vienna have found.

TOMATOES REALLY HAVE LOST THEIR FLAVOUR

Spanish researchers have found that constant breeding for size and yield has caused a loss of 13 volatile compounds responsible for the fruit's distinctive tangy taste leaving our tommies watery and insipid.

BURSTING BALLOONS ARE LOUDER THAN SHOTGUNS

Next time you find yourself at a party, you might want to step away from the balloons. Popping balloons can make bangs up to 168 decibels, four decibels louder than a 12-gauge shotgun, a team at the University of Alberta has found.

PHOTO: S CONWAY MORRIS/JIAN HAN



CAN WE TRUST SCIENTISTS IN A POST-TRUTH WORLD?

In these testing times, we need our science to be solid

It's the big question being asked around the world. In these post-truth, fake news, alternative-fact times, who can we trust?

Most people are pretty sure of one thing: it's not politicians or the media. For years, they've been at the bottom of surveys of trustworthiness. Amazingly, a recent global poll revealed that what little trust they once enjoyed has now plunged to the lowest level ever recorded.

Fortunately, those same polls also highlight the existence of the ultimate source of reliable insight: science. Not surprisingly, the current crisis of trust has prompted high-minded academics to pen pieces insisting it's time we all put our trust in the methods of science.

What's striking about these calls to arms is their naivety. While science has an impressive track record of debunking misconceptions, blunders and plain lies, it doesn't follow that we should therefore put our complete trust in scientists. For that assumes scientists can be trusted to know what they're doing. And sadly, that's just not the case. Too many researchers seem to think that hard data alone is the hallmark of reliable science. Yet hard data from badly designed studies is quite capable of giving compelling support for claims that are just plain wrong.

For example, imagine there's a new idea for reducing juvenile crime: take the worst offenders to a tough jail to see what awaits them if they don't mend their ways. To test the idea, we can simply check to see if the visits trigger a fall in re-arrest rates among those taking part.

Chances are the data will show the idea works – but that doesn't mean it actually does. That's because of an effect that's called 'regression to the mean', which rears its head when dealing with extreme cases.

Those young offenders were chosen to take part precisely because they were arrested an extreme number of times. But that's partly the result of chance: they just ran out of luck too often. Once they've had their prison visit, their spate of bad luck is likely to 'regress' back to a more average rate. As a result,

"TOO MANY RESEARCHERS SEEM TO THINK THAT HARD DATA ALONE IS THE HALLMARK OF RELIABLE SCIENCE"

they'll evade re-arrest – and thus appear to have mended their ways, when in reality they haven't.

This isn't some esoteric possibility either. For decades a scheme called Scared Straight was used in the US following claims it dramatically cut re-offending rates. It's now clear that the apparently rock-solid evidence was anything but. When the idea was tested using studies designed to cope with regression to the mean, the benefit vanished. Indeed, a major review of the evidence published in 2013 showed it was actually worse than useless, and increased offending rates.

Over the years, regression to the mean has fooled researchers in fields from medicine and business to psychology and finance. Which wouldn't be so bad, except the phenomenon has been known about since Victorian times.

And that's one of the striking things about these traps. Warnings about them have been circulating for years, seemingly with little effect. That's because many – perhaps even most – working scientists have a surprisingly poor understanding of how to avoid the many pitfalls in turning data into reliable insights.

To be fair, a lot of scientists recognise this. A recent poll in the journal *Nature* ranked 'better understanding of statistics' top among factors that would lead to more reliable science.

There has never been a greater need for trustworthy evidence on issues that affect us. The scientific process is without question the best way to gather such evidence. But those claiming to use its techniques need to up their game if they are to justify our trust in them. 📊



Robert Matthews is visiting professor in science at Aston University, Birmingham.

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INNOVATIONS

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MARCH 2017

EDITED BY RUSSELL DEEKS



DRONING ON

Uber uses UAVs for ads

As if the traffic wasn't bad enough in Mexico City, these commuters have to put up with these ad-toting drones too. The slogans carried by the UAVs are urging people to use their cars less, and use Uber instead – the ad at the front says "This is why you never see the volcanoes," a reference to the smog blocking out the vistas in the city. The makers of the ride-sourcing app see Central and South America as a key area for growth and, true to form, are utilising the very latest technology to get their message directly to potential users.

While it's a smart publicity stunt, we can't help but worry about it catching on over here.

FIVE REASONS TO SWITCH

Nintendo is re-inventing the console again...



1. PLAY WHEREVER YOU LIKE

The heart of the Switch is a 6.2-inch touchscreen tablet, which gives you a choice of two configurations: slap it in the supplied docking station and play games on your TV with the two Joy-Con controllers, or take the tablet out of the dock, stick the controllers on the side and bring it with you on your travels. It's not a new idea, but this is probably the best implementation of it we've seen to date. What's more, its games won't be region-locked, so you'll easily be able to play Japanese or US titles.

2. ABOUT THOSE CONTROLLERS...

The Switch's Joy-Con controllers are versatile to say the least. You can attach them to the Grip gamepad; clip them onto the Switch tablet for mobile gaming, as mentioned above; or hold them in your left and right hands, like a pair of Wii remotes. The right Joy-Con is equipped with an infrared motion and distance sensor, which when combined with the HD Rumble force-feedback system enables some truly innovative gameplay mechanisms.



3. GET READY TO RUMBLE

HD Rumble is being described as the most nuanced haptic feedback system currently available. At the console's launch, Nintendo was touting its ability to replicate the subtly different feel of shaking a glass with one ice cube in it, or two. It's this 'high resolution' that makes possible games such as *Milk*, in which players compete to milk a cow – a task that involves responding to the most subtle changes in physical feedback.



4. NO SCREEN REQUIRED

Alongside the new console, Nintendo is introducing the *1-2 Switch* suite of mini-games, many of which are designed to be played without looking at the screen at all (or at least barely). These include *Milk*, mentioned earlier; a safe-cracking game where HD Rumble lets you know when a lock's tumblers fall; and a two-player, Western-themed duelling game.

5. A TASTE OF THE OLD SCHOOL

The starting line-up of games for Switch is solid, if unexceptional. What's perhaps more interesting is that a whole host of NES, SNES and NeoGeo games will also be available for Switch. The Switch was designed to bridge the gap between hardcore and casual gaming; with this announcement, Nintendo's targeting the retro market as well.

FROM TOP TO BOTTOM: The tablet can be placed in a docking station, so games can be played on the TV; *Milk* makes the most of the Switch's haptic feedback system; the right Joy-Con has an infrared camera that detects the shape, movement and distance of objects; the Joy-Con controllers clip into the tablet for on-the-go gaming





VIRTUAL REALITY

You can touch this

With the VR revolution gathering pace, the ability to provide haptic feedback – a sense of touch when you come into contact with objects in the virtual space – has become something of a holy grail for developers. But now, Seattle-based AxonVR thinks it's cracked it.

Debuted in prototype form at CES in January, the AxonVR system involves the user donning an 'exosuit' equipped with thermal and pneumatic microfluidic actuators that apply pressure and temperature to the skin to replicate the feel of virtual objects. The suit is made from a

lightweight, flexible material that AxonVR is calling HaptX, and that it claims can convincingly recreate sensations "ranging from the brush of a butterfly's wings to the impact of a punch... from the warmth of a cup of coffee to the chill of a snowball".

Sadly, though, there's no word yet as to an actual release date. While consumer products such as gaming systems are a long-term goal, it's thought the technology is likely to first find real-world applications in such areas as product prototyping, rehabilitation for medical patients and military training simulators.

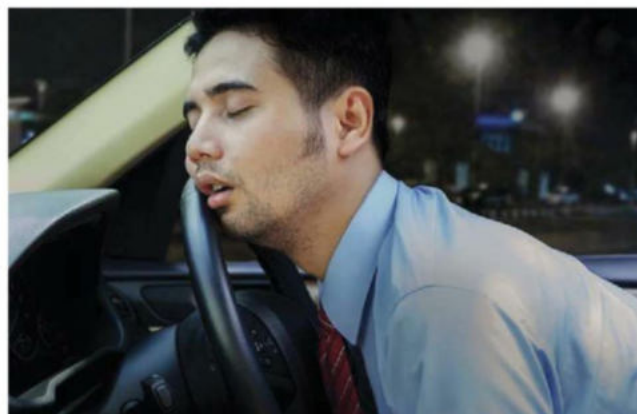
CARS

Drowsiness detector

US companies Freer Labs and Changhong Research Labs have joined forces to create a car headrest that can read a driver's brainwaves and alert them if they're in danger of falling asleep at the wheel.

The technology involved is described by the companies as a "non-contact neuro-bio monitor". In essence, it's an electroencephalogram (EEG), but without the need to stick any sensors to your scalp. The system is able to detect the user's levels of concentration on the task in hand – ie, driving – and if said levels start to dip, will provide an alert via an as-yet-unspecified feedback mechanism, perhaps sounding an alarm or shaking your seat to jolt you back to full alertness.

Two unnamed car companies – one in the US, one in the UK – are currently trialling the headrests, but it's likely to be a while before they're built into any vehicles available to the public.



HEALTH

Wrist doctor

Could smartwatches tell you you're about to get ill, before you get any actual symptoms? That's what a team of researchers at Stanford University has been investigating – and the answer, it appears, is 'yes'.

The team used the sensors in an Intel Basis Peak smartwatch to gather biometric data from 40 volunteers over two years, and found that when we're about to develop an infection, our pulse rate and skin temperature tend to be elevated up to three days before it sets in.

Intel has since discontinued the Basis Peak, but the research suggests a more useful future for wearables where users can be alerted if they're about to get ill.



WANTED!



EDITOR'S
CHOICE



EINSTEIN A-GOGO

PROFESSOR EINSTEIN

Who hasn't always wanted their own animatronic Albert Einstein? This walking, talking robotic recreation of the famous physicist connects to an app on your iOS or Android tablet to play educational science and maths games, as well as functioning as a personal digital assistant à la Siri, Cortana or Alexa. The robot has already exceeded its Kickstarter funding target, and should start shipping in April.

\$598 (£480 approx), professoreinstein.com

THE STYLOPHONE IS REBORN

STYLOPHONE GEN X-1

The popular 60s musical toy gets a 21st-Century makeover. The new Gen X-1 version takes the basic analogue synth that sold over three million units between 1968 and 1975, and adds the kind of sound-shaping capabilities you'd find on a 'proper' synthesizer, including envelope, delay and filter controls, plus a low-frequency oscillator with rate and depth knobs and a choice of square and sawtooth waveforms. If the original was good enough for David Bowie, Kraftwerk and Orbital, just think what you could do with this!

£60, dubreq.com



PIGS WILL FRY

BACON EXPRESS

While we don't find cooking an English breakfast particularly taxing, we're oddly drawn in by the Bacon Express – essentially a 'toaster' for slices of ex-pig. There's a dial on the side to select the cooking time, while inside the machine up to six strips of bacon hang vertically so that the fat drips off, making for a healthier meal.

£32, nostalgiaelectrics.com



CRASH-PROOF COPTER

NIMBUS 195

Ever fancied buying a drone, but been put off by the certain knowledge you'd crash and smash it in about five minutes flat? The Nimbus 195's chubby body is built from tough but lightweight carbon fibre, while its propellers are made of flexible plastic. The result is a drone that can fly full-pelt into a wall or be run over by a car, and still live to tell the tale. It's waterproof, too.

\$750 (£600 approx), aerodyne-rc.com

T20:T20 VISION

FUJIFILM X-T20

This X-T20 camera replaces the X-T10 in Fujifilm's APS-C range. It's got a 24.3MP sensor, and now shoots 4K video at a frame rate of 30fps. It's equipped with a touchscreen LCD viewfinder that can be rotated if you need to shoot at awkward angles, and offers fast autofocus of 0.06s, with a choice of five modes for tracking moving objects. If that doesn't suit, then also new from Fujifilm are the X100 fixed-lens compact at \$1,300 (£1,050 approx) and the mirrorless, medium-format GFX-50S at \$6,500 (£5,253 approx). **\$900 (£720 approx, body only), fujifilm.com**



BREATHE EASY

ONE-LINK ENVIROCAMI

Baby monitor cameras are ten-a-penny, but this one will do a lot more than just let you keep an eye on your child while they're sleeping: it can also reassure you that they're breathing properly. Its 1080p night-vision camera detects the tiny movements kids

make as they breathe and uses this information to track their respiration rates, while built-in environmental sensors also monitor the room's temperature, humidity and carbon monoxide levels.

£TBC, firstalert.com

APP FEED



NASA Science Investigations: Plant Growth

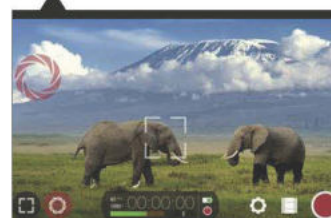
Roam freely around a faithful recreation of the ISS, and grow some vegetables while you're at it.

Free, iOS/Android



Filmic Pro

Lets you apply studio-quality post-production techniques to video shot on your iPhone 7 – though you'll need to put some work in if you want good results. **£9.99, iOS**



Run The Solar System

Learn about the planets and asteroids as you build up to a 10K run, with this immersive training app for runners developed by the British Science Association. *Free, iOS/Android*



ALEXA COMES HOME

Lately, Amazon's voice assistant has escaped the confines of the Echo speaker and embedded itself in countless other devices all around the house. Here are some that caught our eye...

IN THE LIVING ROOM



LENOVO SMART ASSISTANT

If Amazon's own Alexa hub/speaker Echo pleaseth not thine eye, Alexa is also available in similar devices from several other manufacturers. We like Lenovo's Smart Assistant because it comes in a range of colours, and because for £40 more than the standard edition you can get a version with a built-in 5W tweeter and 10W woofer from Harman Kardon. **\$129/\$179 (£105/£145 approx), lenovo.com**



AMAZON FIRE TVS

Under its Westinghouse, Element and Saiki brands, Tong Fang Global is launching new 4K TVs later this year that integrate Alexa with the Amazon Fire TV operating system. So if you want to use services like Hulu or Netflix, there will be no more hunting for the remote – just tell the TV what you want it to do. The sets will also be able to handle search commands like 'find me sci-fi movies featuring Ryan Gosling'.

ETBC, westinghouse.com

IN THE KITCHEN



LG SIGNATURE INSTAVIEW DOOR-IN-DOOR REFRIGERATOR

Announced last year, LG's smart fridge already had a 29-inch touchscreen built into the door to serve up recipes, news, and travel and weather information. Now it's also Alexa-enabled, so if you realise you're running out of milk or eggs, you can order more by simply telling Alexa to do so.

ETBC, lg.com

EVERYWHERE

SAMSUNG POWERBOT VR7000

The trouble with existing robot vacuums is that, while you don't have to push them around any more, you do still have to press a button to start them up. The horror! Thankfully, future generations will be saved from this drudgery now that Samsung has added Alexa integration to its latest robovac. Just *think* what you can do with all that extra spare time!

ETBC, samsung.com



IN THE NURSERY

MATTEL ARISTOTLE

This is an Echo replacement designed especially for kids. As well as running Alexa, Aristotle has a second, child-friendly voice assistant that can play games, lead singalongs and even give foreign language lessons. It also doubles as a baby monitor, and can detect when your little 'uns wake up and soothe them back to sleep with a lullaby.

\$300 (£240 approx), mattel.com



IN THE BATHROOM

SMART & BLUE HYDRAO FIRST

Launched in France last year, this smart showerhead has a built-in LED light that changes colour to tell you how much water you've used. As it rolls out internationally, Smart & Blue has now added Alexa integration, so as you towel off afterwards you can find out exactly how much that shower just cost you.

€90 (£80 approx), hydrao.fr

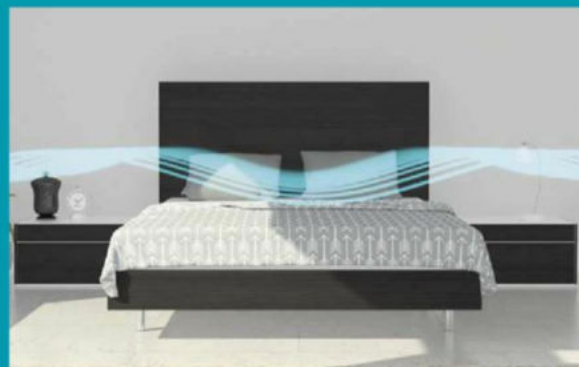


IN THE BEDROOM

C BY GE TABLE LAMP

It may look like a Dyson desktop fan, but GE's new circular LED lamp is actually an Amazon Echo replacement for the bedroom. Or any other room you care to put it in, really, but the alarm function rather lends itself to the boudoir.

£TBC, cbyge.com

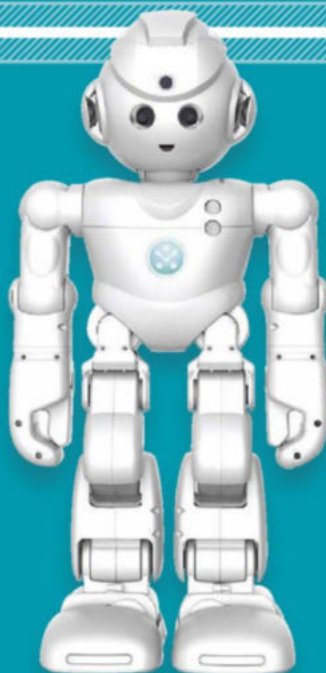


IN THE STUDY

UBTECH ROBOTICS LYNX

Another Echo alternative, this humanoid robot has motion detection, a security camera and several music streaming services built-in, as well as the Alexa voice assistant. There's also face recognition, enabling it to tailor its responses depending on who it's speaking to. It's not cheap, though: the retail price is expected to be in the region of \$800-\$1,000, compared to the Echo's \$180.

£TBC, ubtrobot.com



NIGHTINGALE

Having trouble sleeping? Nightingale is a sleep aid from Cambridge Sound Management that'll soothe you to sleep by masking traffic noise, barking dogs and so on with your choice of 15 different 'sound blankets' – and now, thanks to Alexa, you can turn it on and off just by speaking to it. Sweet dreams.

\$249 (£200 approx), meetnightingale.com

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MESSAGE OF THE MONTH

Mind games

Following the article concerning the brain in the February issue (p54), I would like to make the following observation. I have long been convinced that learning to play the game of bridge and playing it regularly will keep Alzheimer's at bay. There are many bridge clubs up and down the country and a lot of them will have a high proportion of elderly members in their sixties, seventies and eighties, all of them fully *compos mentis*.

Okay, bridge is not a simple game to learn, but the rewards from having done so are manifold. In addition to the mental exercise the game provides, the social interaction also helps to combat this disease. Indeed for some of these players, bridge in their later years has become a way of life.

Alan A Brown, chairman, Yateley & Hawley Bridge Club

➔ Indeed, the social element of physical or mental activities such as ping-pong and bridge seems to be a vital ingredient in the recipe for keeping your mind sharp. – **Ed**



WRITE IN AND WIN!

The writer of next issue's *Message Of The Month* wins a **Groove-e Classic Vinyl Record Player**. This cream-coloured turntable has a 3W amp, speakers and FM radio built-in, and RCA phono outputs for ripping your old vinyl to digital. prezzybox.com



A calculated decision?

Your comments on who invented the computer (January, p98) were wrong on both counts. Ada Lovelace has long been recognised as the real inventor of modern computing. A nationally acclaimed mathematician in her own right, she worked with Charles Babbage for several years on his analytical engine, but unlike Babbage – who saw it as only an advanced calculating machine – she saw its great potential. She wrote several articles on how the engine could be improved to become a programmable computer, capable of arithmetic logic and control of flow loops. Lovelace drafted programs on solving logical complex problems and even wrote programs to compose music. She actually claimed that the engine (as modified by her) could “revolutionise the world”.

RH Bravington, Bognor Regis

➔ Ada did see more potential in the analytical engine than Babbage. But he remains the first to design a machine capable of such feats, and Turing the first to prove its powers mathematically.

– **Robert Matthews**,
science consultant

Lop-sided numbers

Your question ‘Does the average person exist?’ (February, p80) reminded me of a riddle which



Ada Lovelace, 19th-Century computer visionary

asked what feature of the average human body is not possessed by any person in the world, where almost every person on Earth

is above average, and hardly anyone is below average? The answer is the number of arms (or legs, eyes, etc). The ‘average’ human has slightly less than two arms each – taking into account those who only have one, part of, or no arms – and almost everyone has two! This does, of course, take

average as the mean, not mode, but it still baffles most people.

Ron Maslin, Nottingham



These women have
more than an average
number of legs

A frosty reception

In response to your article on cryogenics (January, p54), a concern which I have never seen mentioned – but I suspect is equally valid – is whether you would be awoken by a friendly or hostile society.

Assuming you are resurrected in the distant future... what if you awake in a *Matrix*-like civilisation? Or you are awoken by hungry aliens that like to feed off human bodies? Waking from death in a cryogenic tank, you would be extremely vulnerable. Another concern is that there may be no one able to oversee your welfare, should the cryogenics centre run out of funds and have terminate its support for your body.

That said, the above are only possibilities, whereas death is a certainty. So with cryogenics you still have a better chance of future survival than just being cremated or buried.

Merlin Batchelor, via email

➔ I imagine a hostile, human-eating society probably wouldn't bother to wake you first. At best, they might thaw you out in the microwave. – Ed

When we're dead and gone

With regard to your articles on asteroid impact and humanity's

Space exploration is crucial in ensuring the survival of our species, argues Peter Davey

disappearance from the planet (February), sci-fi author Robert A Heinlein once said: "The Earth is now simply too small and too fragile a basket for the human race to keep all of its eggs in."

Given a big enough impact all human life, perhaps all terrestrial life, could be in jeopardy. If the Earth were rendered uninhabitable, evidence of our previous existence would continue – in orbit, on the Moon, on and around Mars, and so on. *Homo sapiens* is the first creature in the history of the Earth of whom this can be said.

However, as someone once said, "Sometimes the best symbol for something is the thing itself". To preserve a record of the human race is not nearly as satisfying as preserving the human race itself.

There is a rather nasty scientific concept called 'entropy' which suggests that if you don't keep moving forward you will end up going backwards – stasis turns into stagnation. We must keep moving forwards or face the consequences. Making the human race less dependent on the survivability of this planet would increase our own chances of long-term survival. All we need is the will to fulfil the dream.

Peter Davey, Bournemouth



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SUR

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SPACE

OUR EXPLORATION OF THE COSMOS IS HAMPERED
BY OUR BODIES AND MINDS, WHICH STRUGGLE
IN SPACE. SO COULD WE EVER OVERCOME
OUR BIOLOGY AND SETTLE AMONG THE STARS?

WORDS: DR LEWIS DARTNELL



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Y

ou might have thought from watching videos of astronauts aboard the International Space Station (ISS) that spaceships were pretty benign environments. Floating around in microgravity looks like a lot of fun, and as you're isolated from the rest of the human population you're effectively quarantined against catching flu or any other transmissible disease. But in fact, space is pretty harmful to the human body. We evolved as social animals under the conditions on the Earth, and travelling beyond the planet has a number of negative effects on the body and mind.

So what are the main risks encountered by spacefarers, and what does the latest research have to say about how to solve these problems for long-duration missions in the future?

GRAVITY

Freefalling around the Earth in orbit, or coasting through interplanetary space on your way to Mars, gives you the sensation of weightlessness. You're still moving under gravity, but it doesn't load your body, and this has a whole host of knock-on effects. For example, your inner ear can no longer help you orientate yourself, and the redistribution of bodily fluids causes your face to puff up and your eyeballs to distort.

But the long-term effects are more concerning. Without the loading of gravity, your skeleton loses calcium and becomes brittle (like with osteoporosis). Your muscles, especially those involved in supporting your spine and holding you upright, deteriorate and shrink. Plus, your heart becomes weaker when it doesn't have to pump blood upwards. While you remain in a weightless environment, this isn't too much of a problem – and in some senses your body is being adaptive in remodelling itself to life without gravity – but it can be hugely debilitating or dangerous when you return to the surface of the Earth or any other planet.

In the long-term future, the solution might simply be to generate artificial gravity for yourself on a spaceship. If you rotate large sections of a spacecraft – giant turning wheels or cylinders – you can exploit the centripetal force from the inside wall that keeps you moving in a circle to create an apparent gravity. We're well familiar with this idea from sci-fi films like *2001: A Space Odyssey*, or more



**"WITHOUT THE LOADING OF GRAVITY
YOUR SKELETON LOSES CALCIUM
AND BECOMES BRITTLE, AND YOUR
MUSCLES DETERIORATE AND SHRINK"**

recently *Passengers*, but the problem is that the engineering required to build such a large rotating structure in space is pretty challenging.

In the shorter term, spacecraft might incorporate mini-centrifuges. These wouldn't be large enough to walk around or work inside, but they would fit within the existing structure with just enough space for a single astronaut at a time. Spinning relatively quickly, these could generate artificial gravity for short bursts while the astronaut exercises. The idea is that gravity could perhaps be dosed in small amounts; just enough to prevent the body deteriorating in space. David Green and his



FAR LEFT: The Dainese BioSuit has been designed for trips to Mars

LEFT: Danish astronaut Andreas Mogensen tries out the ESA skinsuit on the ISS

RIGHT: In 2001: A Space Odyssey, apparent gravity was provided by a rotating wheel

colleagues at King's College London have been working with MIT and the European Space Agency (ESA) on another solution, the 'gravity loading countermeasure skinsuit'. This skinsuit looks a bit like a triathlete's sleeveless wetsuit, and incorporates a specific weave of elastic material that provides a graded tension between the feet and shoulders. This elastic loading on the body simulates 1g (Earth's gravity) and is designed to help prevent stretching of the astronaut's spine and muscle and bone wasting. The scientists are running tests on their skinsuit on Earth, and it was recently worn on the ISS by Andreas Mogensen, the first Danish astronaut.

What about developing drugs that could help make exercise in zero-g more effective or stop muscle loss altogether by blocking the degenerative process? Nathaniel Szewczyk, at the University of Nottingham, has been involved in research along exactly these lines. But rather than experimenting on human test subjects, he has been using microscopic worms.

Caenorhabditis elegans is a nematode worm, but it has two different muscle types that are similar to the heart muscle and skeletal muscles used for movement in humans. As *C. elegans* is such a simple animal we've already been able to work out exactly how it develops, and we've also sequenced its whole genome. This means that *C. elegans* is a perfect test case for helping scientists understand the effects of microgravity on animal bodies, and they've now been flown on a number of space missions as microscopic astronauts. Szewczyk and his colleagues have found changes in the cellular production of around 100 proteins during spaceflight, many of them involved in muscle-building. "These experiments with *C. elegans* in Earth orbit have enabled us to track how the expression of different proteins responds to weightlessness, and so explore the genetic basis behind deterioration of the body's muscles," he says. "In our current ESA flight we're specifically testing a few drugs to see if they can reduce muscle loss in worms."

So the hope is that in the future, astronauts will be able to pop a pill to help protect their heart and muscles while in space.



RADIATION

Gravity isn't the only thing that the Earth provides for our bodies. The thick atmosphere and global magnetic field that cocoons our planet protects the surface from cosmic rays. These are energetic radiation particles – spat out by flares on the Sun or accelerated to nearly the speed of light by supernova events – that are exceedingly hazardous to cells.

Astronauts aboard the ISS, and in particular any future spacefarers voyaging to the Moon, Mars and beyond

will be exposed to this nasty space radiation. These energetic particles damage DNA causing mutations and could potentially trigger tumours and cancer, and they also turn the lenses of your eyes opaque. But what we understand much less clearly is what irreversible effects cosmic rays might have on your immune system, or on your brain's neurons.

Astronauts can be protected against cosmic rays by providing several metres of radiation shielding to absorb the particle bombardment, and this would be relatively simple on the lunar or Martian surface by burying the crew quarters underground. But providing complete shielding around a spaceship would make it impossibly massive and expensive. So instead of blocking the radiation, another countermeasure would be to reduce its harmful effects within the body. Dietary supplements and drugs could be taken to mop up free radicals produced in your cells by radiation, or to help with DNA repair. The problem, says radiation physicist Dr

Marco Durante, is that current antioxidant supplements aren't particularly effective, whereas radioprotector drugs like Ethyol do work but are pretty toxic. Ethyol, for example, is only occasionally used with patients who have cancer in the head and neck region, where the side effects of radiotherapy are often severe. "The US Department of Defense has developed several compounds in the framework of the homeland security program, and testing these for their effectiveness against cosmic rays in astronauts would be very interesting," Durante says. "As an alternative to drugs, one promising biomedical process is hibernation, because radioresistance seems to be increased at low temperature."

If we can work out how to keep the human body in a state of cryogenic suspension, the crew could sleep through the whole eight-month flight to Mars, and the freezing cold would also help protect their cells from radiation damage. And if the astronauts are not active, it will also mean that the

"WHAT WE

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NEURONS"



demands on the life-support system, and the amount of food and other consumables that will be needed, will also be greatly reduced.

But perhaps we could go one better. Could it be possible to genetically modify future astronauts to enhance their radiation resistance? New research on strange microscopic animals known as tardigrades elucidates one route we might go down. Takekazu Kunieda, a molecular biologist at the University of Tokyo, has been working on these tiny 'water bears' which are known to be able to survive extremely hostile conditions such as the vacuum of space and punishingly high radiation levels. To try to understand which genes might be behind these prodigious survival skills, Kunieda sequenced the tardigrade's genome and then inserted sections of this DNA into mammalian cells in a petri dish. In this way, they found a new gene dubbed Dsup (for 'damage suppressor') which acted to prevent the tardigrade's DNA from breaking under radiation. And astonishingly, this gene also reduced radiation-induced DNA damage by 40 per cent in human cells.

Mars colonists would need to shield their base from dangerous cosmic rays

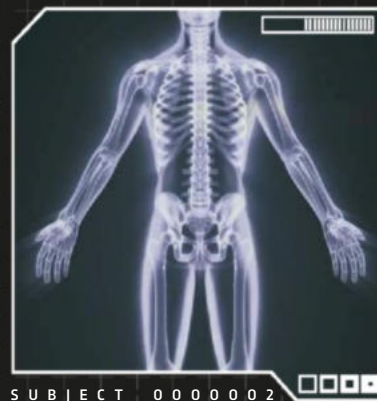


YOUR BODY IN SPACE



SUBJECT 0000001

Your inner ear can't work in microgravity, which can cause dizziness and space sickness.



SUBJECT 0000002

Without gravity, your skeleton loses calcium to become brittle and weak, like with osteoporosis.



SUBJECT 0000003

Long-term exposure to cosmic rays may also impair brain function, which could be critical in an emergency.



SUBJECT 0000004

Conditions aboard spacecraft can lead to insomnia, loss of appetite, anxiety and depression.



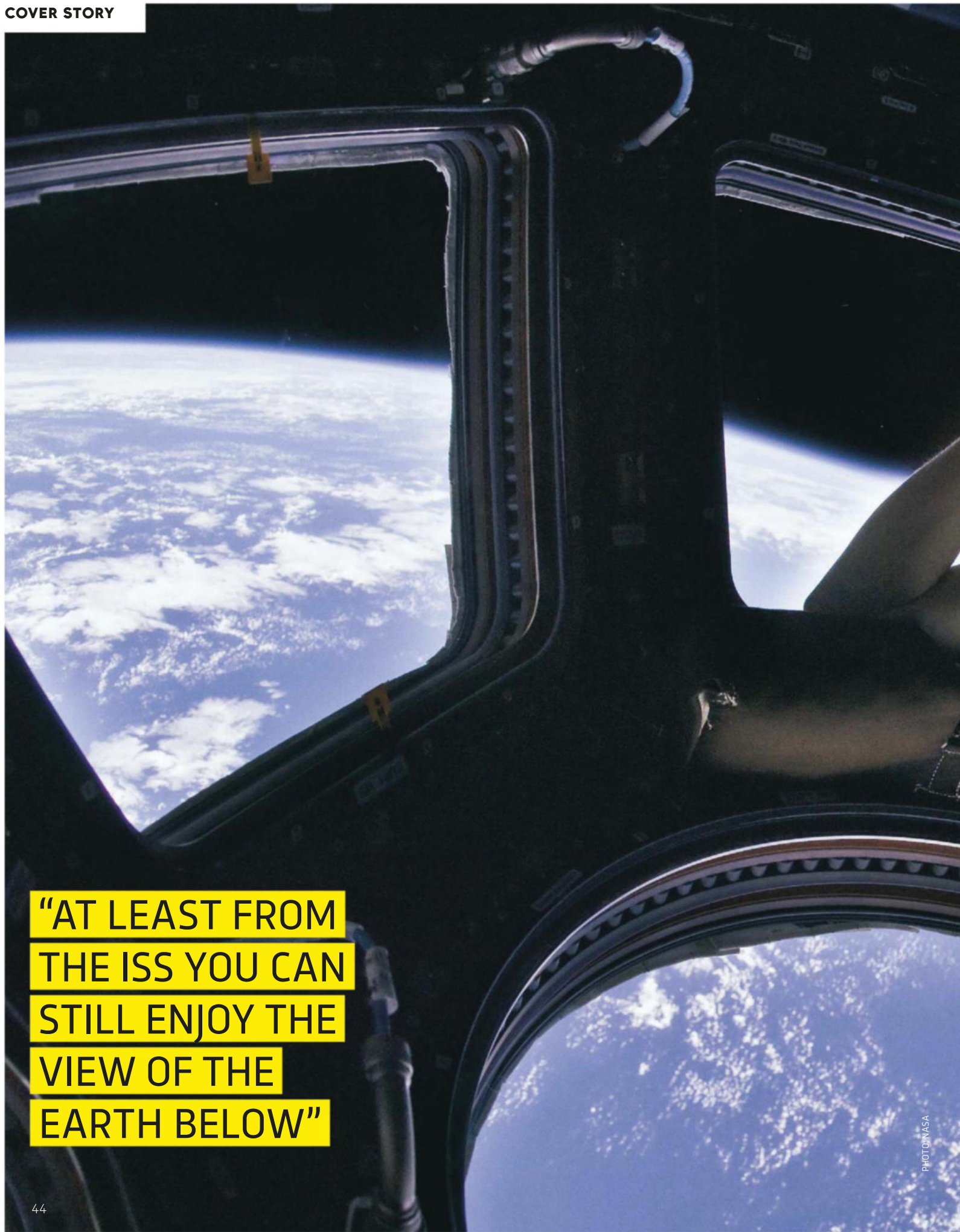
SUBJECT 0000005

Redistribution of body fluids in zero-g makes your face puffy. Your eyeballs distort, blurring vision.



SUBJECT 0000006

As your heart no longer needs to pump blood up against gravity in zero-g, it weakens and deteriorates.



"AT LEAST FROM
THE ISS YOU CAN
STILL ENJOY THE
VIEW OF THE
EARTH BELOW"



Privacy tends to
be in short supply
aboard the ISS





PSYCHOLOGY

Long-duration space travel can take a heavy toll on your mental well-being. ISS astronauts often report problems with insomnia and loss of appetite, and it can be hard to find any privacy in the confines of the craft. Crews also have to be carefully selected to make sure that every member is easygoing – there is the constant threat of something going wrong, and you can't risk astronauts irritating each other too much. It's not like you can diffuse an argument by avoiding each other or stepping outside for some air! You have to spend months on end with the same people, isolated from all your loved ones at home.

At least from the ISS you can still enjoy the view of the Earth below – on a mission to Mars the feeling of remoteness will be even stronger. And the signal delay time of up to 40 minutes will mean that you'll not even be able to talk to anyone on Earth – all contact will be by email or video message.

These psychological issues are tricky to detect early on, and when you're investigating the effects on group cohesion it's hard to think of scientific ways to measure the outcome. While medical tests might be able to reveal the physiological effects of spaceflight on your body, people might be less inclined to self-report on psychological stresses or problems they are encountering. NASA has been paying particular attention to these psychological effects. In a 2016 report on human health risks, they highlighted several areas needing further study. These include the effects of long-term disruption to sleeping patterns and 'circadian rhythm desynchronisation'. This is when your body's internal cycles of temperature regulation, metabolic activity, and wakefulness, for example, are forced out of rhythm with each other – you're probably familiar with this from jet-lag. But what are the effects of experiencing desynchronisation for months or years of a lengthy space mission? The report recommended more

ABOVE: The team at Antarctica's Concordia Station are more isolated during winter than ISS astronauts

research into how diet and nutrition can affect these circadian rhythms, and whether the timing of meals, for example, might help solve the problem.

One of the best ways of studying psychological effects is in similarly isolated situations back on Earth. Dr Beth Healey has spent more than a year on the Concordia Station in the icy depths of Antarctica, as the ESA's research doctor. During a polar winter you don't see sunshine for three months, and no evacuation is possible even in an emergency – in this sense the Concordia scientists are more isolated than ISS astronauts. In one of Healey's experiments, she got the crew to wear trackers. These monitored how mobile each person was, and who they interacted with. "This provided valuable information regarding how group dynamics changed over time and could identify critical time points in the mission where crew members may be more likely to isolate themselves or seek out social interaction, or when conflicts were most likely to occur," she says.

Healey also worked on developing a 10-part cognition test, which is now likely to be adopted into the astronauts' routines aboard the ISS. "The test looks at lots of different variables, for example risk-taking behaviour, reaction times, memory testing, and so on. The astronauts would take this regularly, and any dip in performance would prompt mission control to investigate," she explains.

FOOD AND NUTRITION

Weightlessness presents several problems for eating in space. Without gravity, crumbs are a real health hazard, floating in the air to be inhaled into your lungs. And the redistribution of bodily fluids mean tissues in your head swell and you struggle to smell or taste things properly – just like having a cold. So astronauts often prefer spicy foods, and tend to eat breads like tortillas that don't crumble. Practically all the food on the ISS is pre-packaged and is simply rehydrated and heated up – imagine eating nothing but airline food for months on end. Every six months or so a resupply vessel is launched from Earth to deliver essential stocks. It's stuffed with food, water, spare clothes, fuel, oxygen and so on.

But for longer space missions, such as a Moon base or mission to Mars, constant resupply would be prohibitively expensive or outright impossible. We've seen already how hibernation technologies in the future may allow crews to sleep on the way to Mars, and so relieve the necessity for a large amount of travel food, but when they wake up on arrival, food will once again be a priority. Instead of relying on deliveries from Earth, Mars colonists would need to learn to be self-sufficient – to become space farmers!

In the film *The Martian*, Matt Damon's character cultivates potatoes in regolith (the powdery rocky surface) mixed with his crewmates' excrement to provide nutrients. And this isn't too far off the truth of what space agencies are considering for habitats on Mars (minus the poo). For example, last year scientists at Wageningen University in the Netherlands made simulated Martian soil and tested which crops could be grown in it. They found that tomatoes, peas, radishes, rye and rocket grew well, but spinach struggled. They are now testing whether potatoes and beans could be cultivated on Mars. The environment is so hostile you would need to provide pressurised, inflatable greenhouses, but scientists remain hopeful that future Martians could live off the land.

And what about meat? Keeping farm animals on an off-world base would be enormously difficult – they would take up a huge amount of space and resources. So instead, future space explorers are likely to be mostly vegetarian, and get small amounts of animal protein from bugs. Insects can be reared in high-density and fed on plant waste. Taikonauts on China's Tiangong-2 space station have been raising silkworms, which could serve as a protein-rich source in the future. So perhaps future Martians will be eating bug burgers in home-grown wheat buns with lettuce and tomato! 🐛



RIGHT: ISS astronauts rely on deliveries of fresh food to top up their supplies, but this wouldn't be feasible on a Mars or Moon base

BELOW: From left to right, radishes grown in Moon soil substitute, Mars soil substitute, and Earth soil



**"MARS COLONISTS
WOULD NEED TO
LEARN TO BE
SPACE FARMERS!"**



Prof Lewis Dartnell is an astrobiology researcher at the University of Westminster and author of *The Knowledge: How To Rebuild Our World After An Apocalypse*.

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YOUR QUANTUM BRAIN

A new theory suggests that the bizarre world of quantum physics could be at play between our ears

WORDS: ANDY RIDGWAY



Quantum physics is weird. It's a world in which microscopic objects can be in two places at once. Where objects can be made to teleport from one place to another, and where they can mimic one another – even when they are kilometres apart. It's the fairyland of physics where almost anything seems possible. And some of these strange happenings could be taking place in *your* brain. Right now.

The idea that the way our brains function is down – at least in part – to quantum processes is not new. But it has often been derided too: how could we be harnessing fragile quantum processes in our brains, say many scientists, when they are so warm, wet and messy? After all, quantum computers need to be cryogenically cooled to near absolute zero (-273°C) to work.

But a theoretical physicist in the US says he has found a 'loophole' that would allow quantum processes to take place inside our noggins and not only that, these quantum processes are

intrinsically involved in how our brains function – bestowing us with abilities such as memory, and maybe even consciousness itself.

Matthew Fisher, professor of physics at the University of California, Santa Barbara, has come up with a specific mechanism, made up of a series of quantum and biological cogs. He says that this is what makes us tick. And he's putting his ideas on the line by drawing up a series of experiments that would prove whether he's right or wrong, including building a quantum brain in a test tube.

PERSONAL INSPIRATION

Fisher has a PhD in theoretical physics and worked at IBM and Microsoft developing quantum computers, and also had a stint at Caltech. His interest in what goes on in our minds came from his experiences with chronic depression. "I've been on medication ever since I was 26," he says. "I've always been fascinated as to how taking a pill can modify the tenor of one's conscious state. I'm not talking about being high, like being on drugs." ➤

• Back in 1986, Fisher plunged into a cloud of depression that didn't shift for two years. It was only an antidepressant prescribed by a psychiatrist that lifted it. "Really for me it was like being reborn after two years of depression."

So what's going on and how does it work? Fisher wanted to find out. Rather than studying complex antidepressants, such as Prozac, he started with lithium – a simple element. "Four years ago, together with Wikipedia and Google, I sat down to learn all about lithium," he says.

He quickly discovered that there are two isotopes of lithium, lithium-6 and lithium-7, which differ only in the number of neutrons in their nuclei. "It seemed very unlikely that they would have different biological effects because the chemistry involves the number of electrons on the atoms, which is the same for both isotopes, and should be largely unaffected by what's going on in the nucleus," he says.

But Fisher found a research paper that appeared to show otherwise. Back in 1986, researchers at Cornell University gave the two different lithium isotopes to rats. "When the mother rats were given lithium-7, their moods were kind of dumbed down – they didn't build nests or nurse much. Remarkably, the lithium-6 rats groomed and nursed frequently and their alertness levels were

"FOUR YEARS AGO, TOGETHER WITH WIKIPEDIA AND GOOGLE, I SAT DOWN TO LEARN ALL ABOUT LITHIUM"

high. I looked at these results and thought, 'now that's a drug I want!'"

The study has had Fisher thinking ever since. "You almost immediately have to start thinking about the nuclear spin because lithium-6 has the remarkable characteristic that its spin is isolated from the surrounding environment."

Nuclear spin has nothing to do with a nucleus actually spinning, it's simply a measure of how much the nucleus interacts with electric and magnetic fields. The less it interacts with them, the less it's disturbed by them – something that would come in handy when you're looking for stable properties in your particles in the brain, a place where there are plenty of electric fields. Experiments show that lithium-6 can hold out for five minutes before being disturbed by electric and magnetic fields. To use the parlance of quantum physics, lithium-6 has a 'decoherence' •

BELOW: Prof Matthew Fisher is researching the quantum brain, and aims to build a one in a test tube



PHOTO: SONIA FERNANDEZ/UCSB

LIVING IN A QUANTUM WORLD

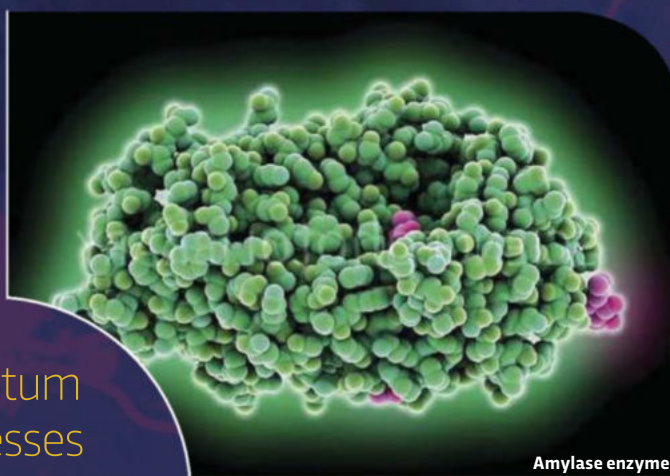
BIRD NAVIGATION

Each year, birds migrate thousands of kilometres using the Earth's magnetic field to guide them. There is mounting evidence that quantum processes are at the heart of this in-built GPS. One theory is that light particles hitting a bird's eye set off a chain of events resulting in the spins of two electrons becoming correlated – and this correlation is sensitive to Earth's magnetic field. This quantum effect alters the signals sent to the bird's brain.



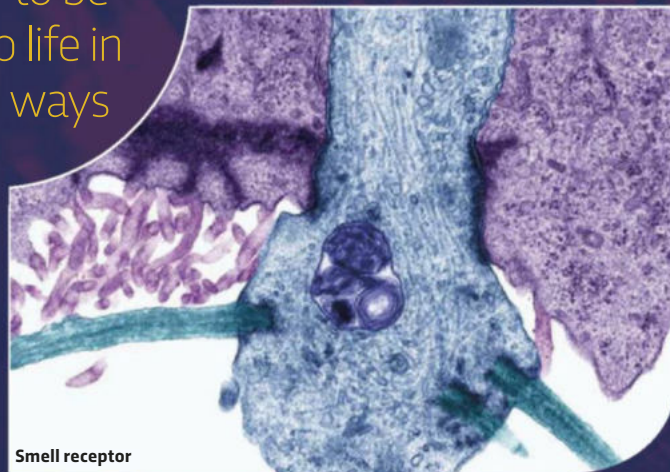
ENZYME ACTIVITY

Exactly how enzymes speed up reactions has always been unclear. One suggestion is that quantum tunnelling could allow a particle to move around without having to overcome a seemingly impossible energy barrier as it just tunnels through it. In the context of enzymes, this means reactions in our cells can take place with a lower energy input, making them more likely to occur, and accelerating the overall reaction speed.



Amylase enzyme

Quantum processes appear to be linked to life in bizarre ways



Smell receptor

PHOTOSYNTHESIS

We've got a pretty good handle on how plants turn sunlight into energy, but what's not clear is how they do it so efficiently. One idea is that they enlist quantum superposition, which is the ability of particles to exist in different positions, have different energies or be moving at different speeds at the same time. This would allow light energy to be transferred to the plant's reaction centre by every route at the same time. Truly bizarre.

SENSE OF SMELL

What goes on inside our nostrils is controversial, but some researchers say that the quantum process of 'electron tunnelling' is involved. In the presence of a scent molecule, this theory goes, an electron in one of your nose's smell receptors can 'jump' or tunnel into an empty energy level, dumping excess energy into the scent molecule. But this can only happen when the molecule is vibrating at the right frequency, giving each molecule an individual smell.

● time' of five minutes. Might lithium-6's spin be some kind of gateway to a quantum world in the brain, something that would enable it to exploit bizarre quantum phenomena? It's possible, thought Fisher. So he started to piece together how quantum processes and biology might interact in the brain.

INTO THE MIND

His first step was to find a naturally occurring equivalent of lithium, as lithium-6 is quite rare. He needed to find something that was sufficiently immune from outside disturbances. "The only

element found commonly in biology which has a nuclear spin with a long decoherence time is phosphorus," says Fisher. He also thought that the coherence times of phosphorus atoms would be further increased if they formed part of a large molecule known as a Posner molecule. First spotted in bone, there is some evidence that these molecules form in extracellular fluid too – the fluid that bathes the cells in our bodies – and they could shield phosphorus atoms to allow quantum processes to occur in our warm, wet

brains. Together, phosphorus and the protective Posner molecules are Fisher's crucial loophole.

Phosphorus and its spin is what Fisher describes as his "neural qubit". It can undergo transitions between 'spin-up' and 'spin-down' quantum states, just like the 0s and 1s in a conventional computer.

Fisher believes the processing power of our brains might be boosted by a phenomenon known as entanglement. Here, two phosphorus atoms that were nearby at one point continue to mimic one another when they are moved far apart. By having these correlations between atoms, it increases the information that can be stored – it's another way of storing information that conventional computers don't have.

Fisher says entanglement may be involved with memory. "The way we recall memories is very associative," he says. "Having an awareness – that we can be sentient beings – may involve entanglement too. I am not the first person to suggest that."

Perhaps the most high-profile scientist to suggest that our consciousness has a quantum origin is Prof Sir Roger Penrose at the University

of Oxford. This mathematical physicist's distinguished career has been mainly focused on untangling the properties of space-time, and has included collaborations with Stephen Hawking. In the early 1990s, Penrose worked with anaesthetist Stuart Hameroff, now an emeritus professor at the University of Arizona, to develop a quantum brain theory.

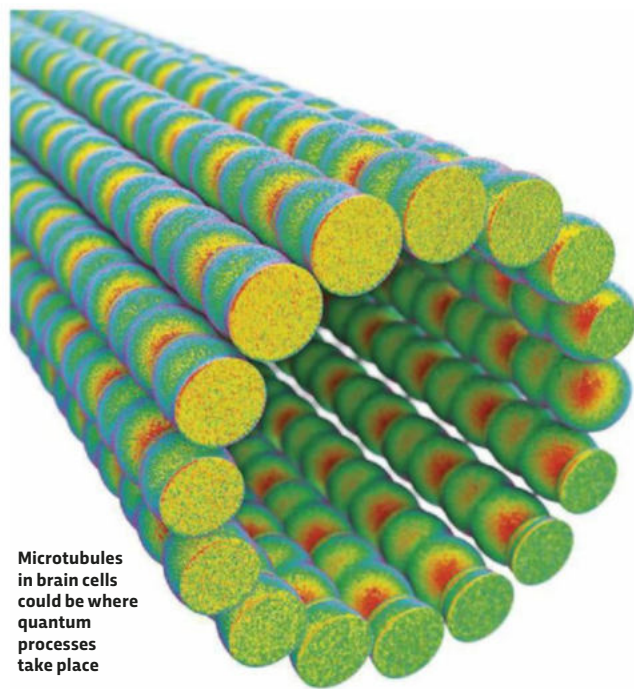
They suggested that quantum processes take place in structures called microtubules inside brain cells – and these structures, Posner molecules, shield the fragile quantum mechanisms. Penrose is open to Fisher's ideas too. "It's very appealing to me what he's doing and it may well be part of the whole story – it looks a promising set of ideas," he says.

GROWING EVIDENCE

Since Penrose and Hameroff first proposed their ideas, there has been growing evidence that weird quantum phenomena *do* play a role in some biological phenomena, such as bird navigation. Nevertheless, any suggestions that quantum processes are involved with brain function – especially something as complicated as consciousness – are greeted with a hefty wedge of scepticism by many neuroscientists.

"If you multiply complexity with complexity, all you get is complexity," says György Buzsáki, professor of neuroscience at New York University. It's a sentiment Dr Alexandra Olaya-Castro, who researches the role of quantum processes in biology at University College London, would

"THERE HAS BEEN GROWING EVIDENCE THAT WEIRD QUANTUM PHENOMENA DO PLAY A ROLE IN SOME BIOLOGICAL PHENOMENA"



Microtubules in brain cells could be where quantum processes take place

agree with. "I think quantum effects will explain certain functions in our brain, but we don't even understand what consciousness is."

Olaya-Castro is sufficiently interested in some of Fisher's ideas to plan her own feasibility study into them. "I think it's plausible that you could find quantum processes affecting molecular mechanisms in biological systems," she says. "What's more difficult to assess is the direct link between those quantum processes at the molecular level and the functions that are happening at the cellular level or higher." But Olaya-Castro thinks one of the strengths of Fisher's ideas is that he proposes specific mechanisms by which the quantum world influences the biological world.

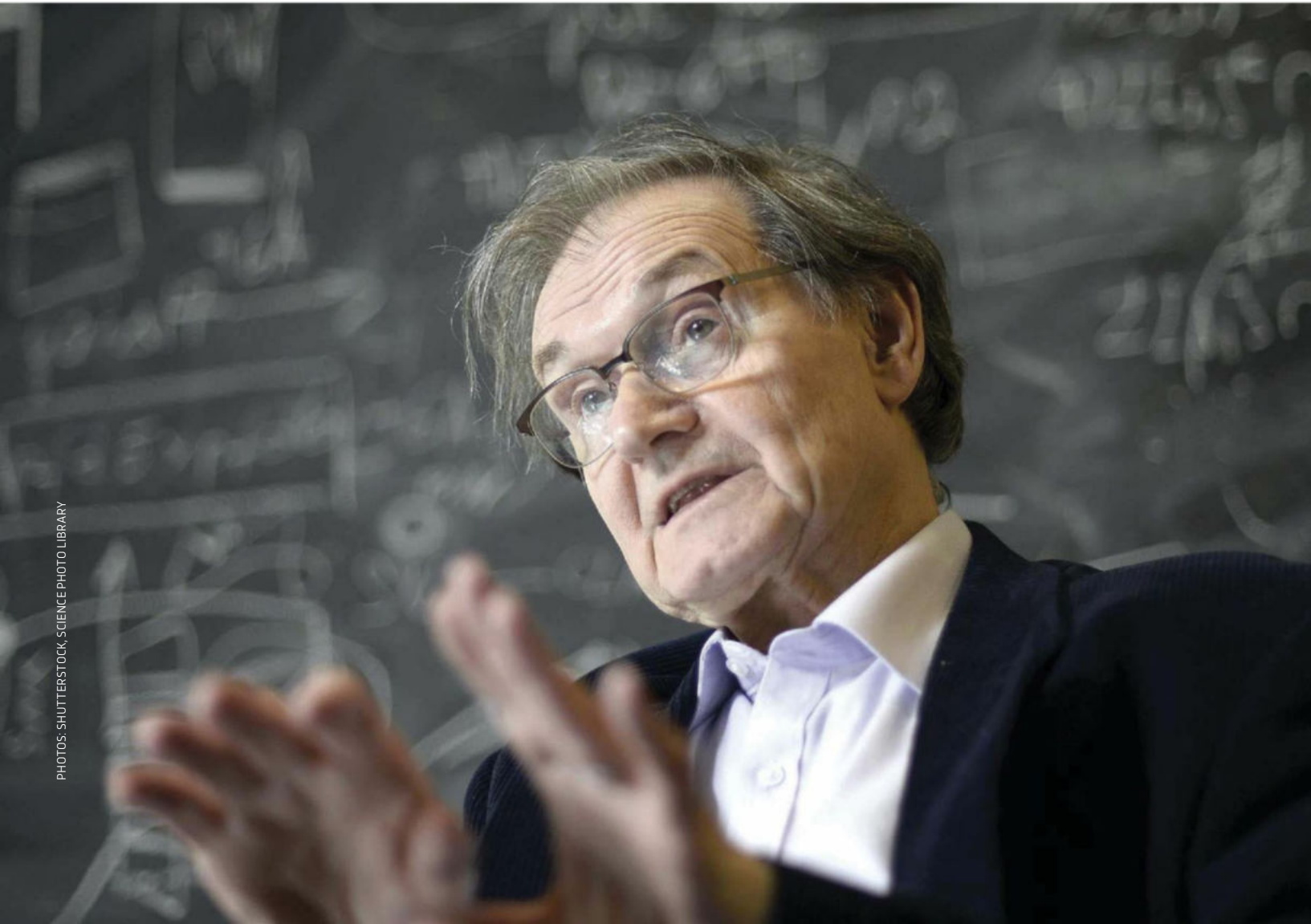
One of Fisher's suggestions is that when an enzyme breaks down adenosine triphosphate – the molecule that cells use to store energy – into adenosine monophosphate, it releases two phosphates. "That would be a crucial step that would hopefully entangle the two phosphate nuclear spins," says Fisher. If these are encapsulated in protective Posner molecules and

'linked' by entanglement even if they are far away from one another in the brain, it could influence how brain cells behave.

Fisher's current goal is to try to piece together evidence for his ideas. His starting point was to try to replicate the 1986 experiment in rats while he was on a sabbatical at Stanford University. But the results were inconclusive. He plans to try again, with a differently designed experiment. He's also designed a string of other experiments that would test each step of his quantum-biological mechanism.

One of Fisher's most ambitious experimental ideas is to try to recreate a simple quantum brain in a test tube. It would consist of extracellular fluid mixed with some of the key cogs in his mechanism, including Posner molecules. He would then add a fluorescent marker to monitor what's going on inside the test tube before pouring half the contents into another test tube placed at the other side of the lab. "What would be amazing is if the fluorescence coming out of these two test tubes on opposite sides of the room were correlated with one another. We would be ●

BELOW: Sir Roger Penrose thinks that consciousness could have a quantum origin



“WE MIGHT ACTUALLY NEED A NEW BRANCH OF PHYSICS ALTOGETHER TO FULLY GET A HANDLE ON WHAT’S GOING ON BETWEEN OUR EARS”

● seeing spooky action at a distance. That would be the smoking gun in the test tube.”

Fisher has lined up a team of specialist scientists, such as chemists and enzymologists, to conduct the experiments. But the big challenge is getting funding – he says he’s been “scraping together bits and pieces of money” but he heard back in December 2016 that a \$1m bid for a grant from the charitable foundation W.M. Keck Foundation was turned down. “We really need

some money to do experiments. Perhaps some publicity will help.”

For his part, Penrose needs no convincing that something bizarre is going on in our brains. In fact, he thinks that while quantum processes may well play a role, we might actually need a new branch of physics altogether to fully get a handle on what’s going on between our ears.

“It’s already outrageous to say quantum mechanics is important – what I’m saying is that it’s not just that – we are looking at the limits of quantum mechanics where it begins to break down,” explains Penrose. This new physics would explain things in the netherworld between the quantum physics of the very small and the physics of the large. “It’s where the weird world of quantum mechanics merges into the world we experience.” In other words, our brains may actually be far weirder than we can currently imagine. 🧠

BELOW: Nuclear spin, illustrated here, is a measure of how much an atom’s nucleus interacts with electric and magnetic fields

Andy Ridgway is a science writer based in Bristol.

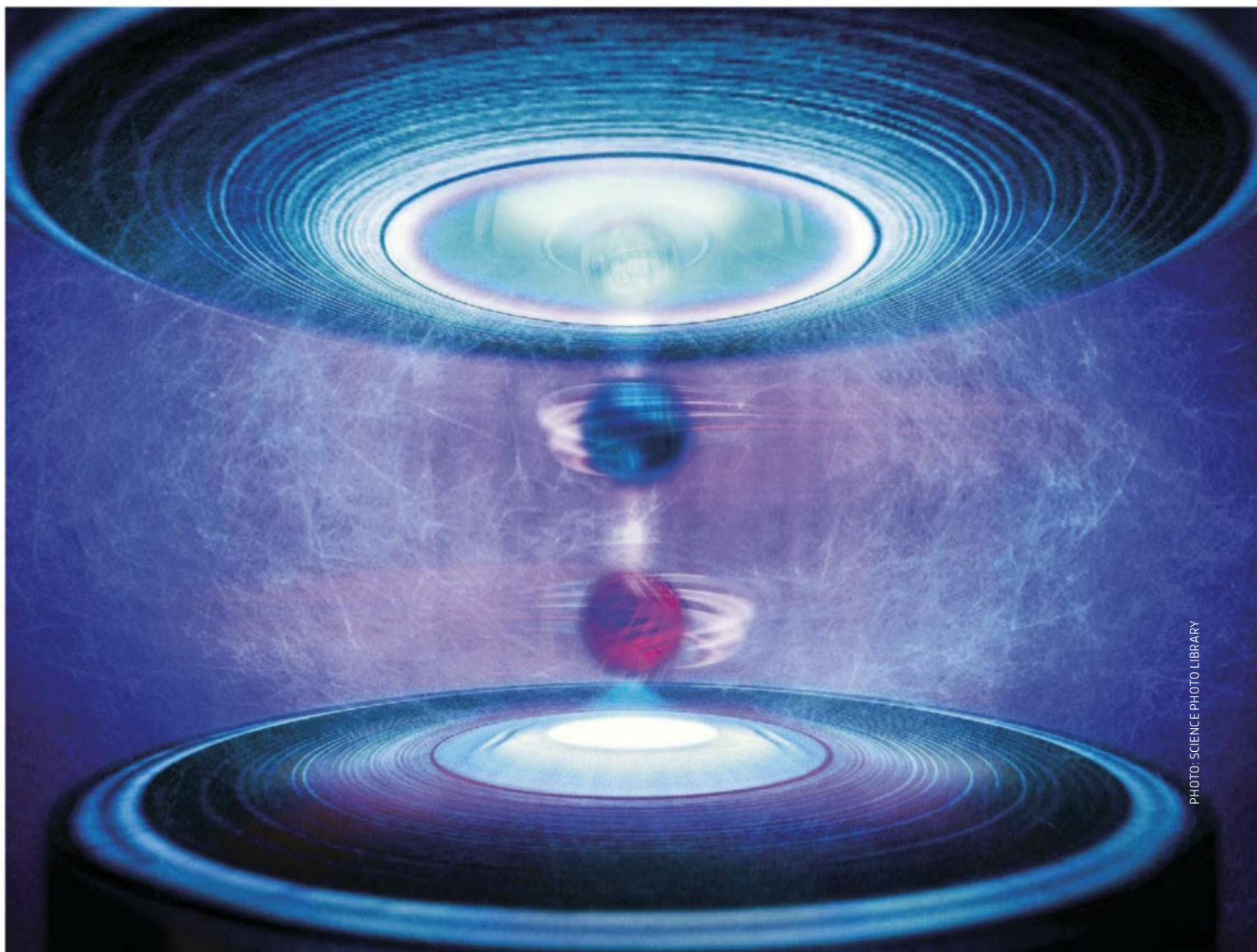
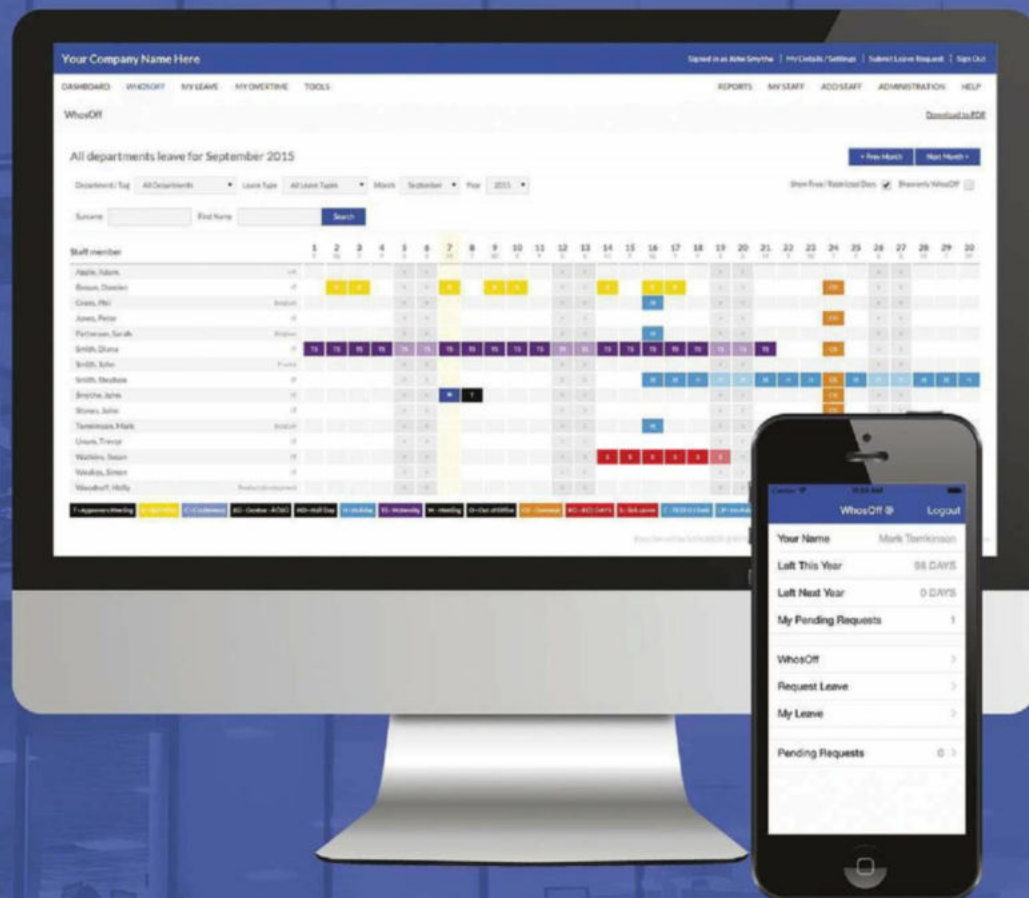


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MIRACLE MICROBES

Mention 'bacteria' and memories of food poisoning and nasty infections probably spring to mind. Yet scientists are finding that microbes can give us much more than a dodgy tummy...

WORDS: TOM IRELAND

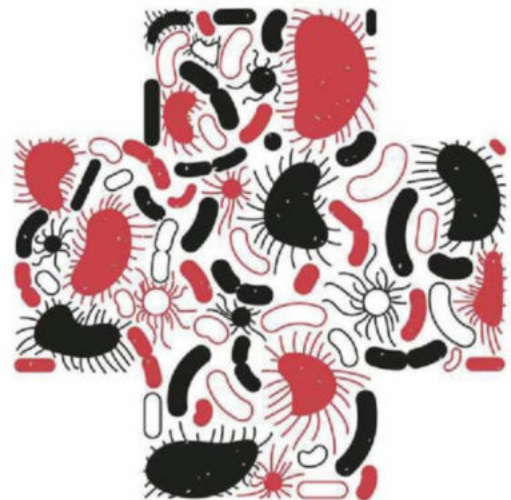


LANDMINE DETECTORS

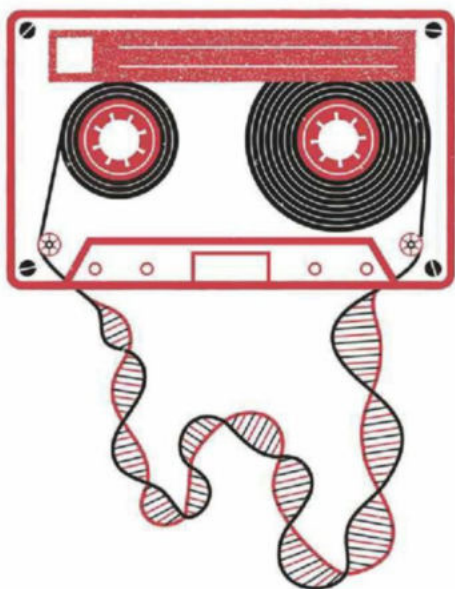
Scientists from Edinburgh University have developed a genetically modified, harmless strain of *E. coli* that glows green in the presence of certain explosives. The researchers hope that the bacteria could be dropped onto suspected landmine sites, potentially replacing the practice of finding mines using metal detectors or sniffer dogs. The modified bacteria produce a protein that binds to TNT, which is found in many landmines. This reaction then 'switches on' a gene that creates luciferase, an enzyme which causes fireflies and other bacteria to emit light.

HEALING HEROES

Could topping up the bacteria in our guts help us recover from injuries quicker? Scientists at Rockefeller University studying mice with spinal cord injuries found that the injury altered the bacteria in the guts of the mice, prompting the release of inflammatory cells. This initiated other processes that impaired their ability to recover from the injury. When some mice were treated with probiotics, they recovered from their injuries faster. The study's authors suggest that when treating spinal cord injuries in humans, changes in the gut could be counteracted with probiotics to assist with recovery.



ILLUSTRATIONS: JAMES OLSTEIN



MICROSCOPIC MEMORY

A team at the Massachusetts Institute of Technology has developed a tool to make bacteria act as 'genetic tape recorders', writing information into their DNA about simple events they have experienced. The bacteria can be programmed to create a new section of DNA when exposed to, say, a certain chemical or light. Researchers can then 'read' the DNA later to find out about what the bacteria experienced. If populations of billions of bacteria are used, the effect adds up to create an analogue organic 'hard drive' of sorts, they say.

BACTERIAL BATTERIES

Minuscule currents caused by the movement of bacteria could one day be used to power nanomachines or tiny electrical components, according to scientists from Oxford University. The team, from the university's department of physics, found that dense solutions of swimming bacteria will spontaneously organise around tiny rotors, forming a microscopic 'windfarm'. Swarm-like activity within this 'living fluid' drives the rotors, providing a tiny but steady source of power that could be used to run the next generation of micromachines, nanobots or smartphone components.



DELIVERY BUGS

Bacteria that navigate using magnetic fields could be used to deliver drugs into tumours. The bacteria, *Magnetococcus marinus*, have a navigation system based on magnetised crystals to help them find their way around the deep sea. Scientists at the National Institute of Biomedical Imaging and Bioengineering in the US have exploited this ability by injecting the bacteria into mice with cancer. They then generated magnetic fields to guide the bacteria towards the tumours. The next step is to modify the bacteria so they can deploy a cargo of tumour-killing molecules.



FIRE FIGHTERS

US scientists are using bacteria to prevent wildfires in Idaho and Oregon. Recently, fires in this area have been exacerbated by the spread of an invasive plant known as cheatgrass, which forms dry and fine straw that catches fire easily in arid conditions. Researchers from the US Geological Survey found that the bacterium *Pseudomonas fluorescens* suppresses the growth of cheatgrass's roots, preventing it from outcompeting native grasses. The land could be cleared of cheatgrass after five years of treatment with the bacteria, the researchers say.

BIOFUELS

US biofuels company Mascoma has created a new yeast capable of converting up to 97 per cent of crop waste into ethanol fuel. This genetically modified strain is significantly more efficient than previous biofuel-producing yeasts, which leave around a third of the tough plant material unconverted. The new yeast works in just 48 hours and its raw materials – corn stalks, wheat straw and the inedible parts of sugar cane – are waste products of commercial farming, so are abundant and cheap.



THERE'S

SOMETHING

IN THE

LEADERS FROM ATHENS, MEXICO CITY, PARIS
AND MADRID HAVE RECENTLY ANNOUNCED
THAT DIESEL VEHICLES WILL BE BANNED IN
THEIR CITIES FROM 2025, DUE TO POLLUTION
CONCERNS. SO WHAT EFFECT DO DIESEL
EMISSIONS HAVE ON OUR HEALTH, AND
SHOULD WE BE WORRIED?

Words: **Prof Robert Matthews**

AIR





Look outside. Perhaps it's a bright and cold day, and you're thinking of cycling into town. But you might want to think again. You may be about to put yourself in harm's way from high levels

of compounds at the centre of a major public health issue: air pollution.

Air pollution has long been regarded as a threat that vanished with the smoke-belching factories of yesteryear. And while the dense 'pea-souper' smogs of the 1950s may have gone for good, they have been replaced by invisible forms of pollution that build up on bright, still days – especially during the cooler months of the year. Exactly how such pollutants affect our health is the subject of urgent research, but there's growing concern that they pose a major health threat. Air pollution is back at the top of the UK public health agenda, implicated in the deaths of tens of thousands of people each year.

According to Prof Dame Sally Davies, chief medical officer for England, it's already clear that the elderly and those with pre-existing heart disease or lung disorders are ►



Listen to *So I Can Breathe*, a season exploring air pollution, 6–12 March.



POLLUTION

particularly at risk. “However, researchers are finding that air pollution may be associated with a much wider range of health conditions,” she says. These include diabetes and neurological disease. Unborn babies can even be affected.

Davies is one of many leading health experts now calling for action. The National Institute for Health and Care Excellence (NICE) has recently unveiled draft proposals on how to tackle the issue, following legal action against the UK government, which has been found to be in breach of European standards for air quality.

HAZY DAYS

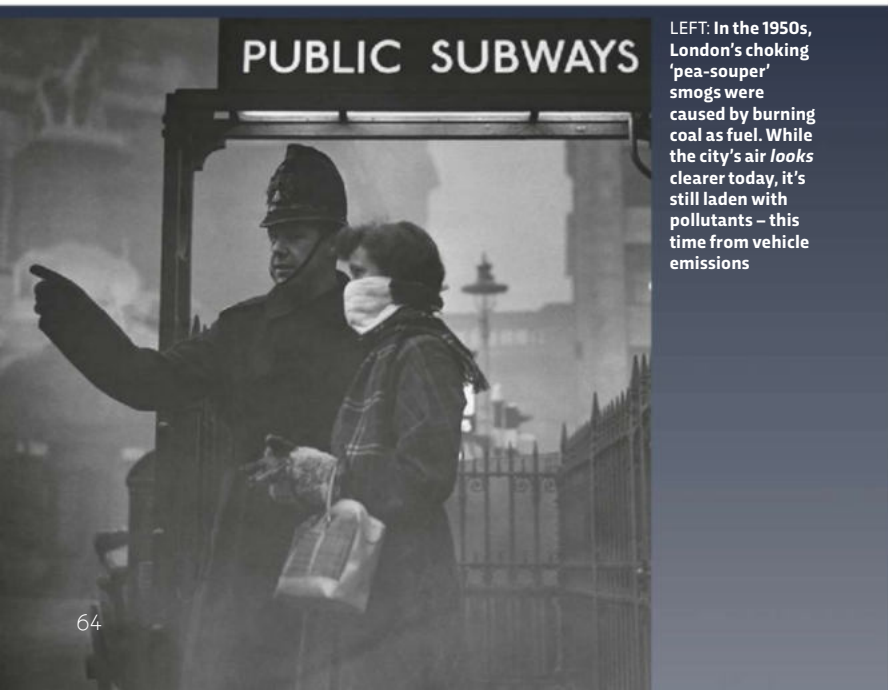
The resurgence of public concern about air pollution has been sparked by the scandal surrounding diesel cars built by Volkswagen. In 2015, the US Environmental Protection Agency (EPA) revealed that the German-based manufacturer had fitted its vehicles with technology that sensed when the car was undergoing an emissions test, and altered its performance to ensure compliance. But once on the road, the car reverted to its normal performance – and far higher emissions of oxides of nitrogen (NOx), one of the pollutants now prompting concern. Yet the scandal came as little surprise to air quality experts. According to Prof Alastair Lewis of the University of York, scientists had expected NOx levels to be declining in city centres as old vehicles were replaced by new, supposedly cleaner ones. “But this was based on cars emitting NOx at the rates suggested by the manufacturers’ test data,” explains Lewis. Following EPA’s revelations, the reason why there had been no decline was all too obvious.

NOx is not the only, or even most harmful, form of pollution emitted by diesel engines. They also spew out so-called particulate matter (PM), tiny specks of carbon laced with organic compounds

While there have been schemes to attempt to clean up London’s air, one road in the city still exceeded 2017’s annual air pollution limit in just five days



“EVERYONE THOUGHT THAT THE PROBLEM OF AIR POLLUTION WAS OVER. BUT HOW WRONG WE WERE”



LEFT: In the 1950s, London’s choking ‘pea-souper’ smogs were caused by burning coal as fuel. While the city’s air looks clearer today, it’s still laden with pollutants – this time from vehicle emissions

like sulphates and metals. Short-term PM exposure causes acute irritation to the eyes, throat, nose and lungs, while people with conditions like asthma can suffer more severe symptoms. But long-term exposure can pose a broader risk, says respiratory medical expert Prof Anthony Frew of the Royal Sussex County Hospital, Brighton: “There’s data suggesting that diesel particles can leave people more prone to allergic responses, and promote inflammation of the airways.”

Studies suggest that PM may pose a particular risk to the elderly and those with heart disease. “It can cause cardiac rhythm issues – though we don’t know if the effect happens immediately on exposure, or takes some time,” says Frew.

Mystery also surrounds the long-term effects of exposure. In a study of the health of over 360,000 people in England and Wales, a team led by Dr Anna Hansell of Imperial College London found that exposure to pollution in the 1970s still



HOW TO PROTECT YOURSELF FROM AIR POLLUTION

Many of us can't avoid the air from our city streets, but there are ways we can minimise its risk to our health

CHECK FORECASTS

Like the weather, UK air quality is forecast every day and the government's UK-Air website publishes maps rating air pollution on a scale of 1 (low) to 10 (high). According to health experts, most people can cope with routine exposure to even moderate levels of air pollution (up to 6), though anyone with respiratory conditions or heart problems might want to reduce strenuous activity if they feel unwell.



affected health almost 40 years later. The team also found that while levels of air pollution are now far lower than in the 1970s, it seems to be more toxic.

Exactly why isn't clear, and some experts have questioned the finding. Even so, there is an emerging consensus that air pollution is a major health hazard. In a report published just before the VW scandal broke, the Department for Environment, Food and Rural Affairs (Defra) put the estimated number of deaths in the UK due to oxides of nitrogen and PM at over 45,000 per year.

It's a shocking statistic – over 25 times the annual number of fatalities on roads. But it has been backed by the Royal College of Physicians and Royal College of Paediatrics and Child Health. Their joint report issued last year stressed that the threat from air pollution has evolved over recent decades.

"Everyone thought that the problem of air pollution was over. But how wrong we were," said Prof Stephen Holgate, chair of the group which put together the study. He believes the time has come for "urgent, determined and multidisciplinary action" to tackle the threat.

CITY SHAKE-UP

Unsurprisingly, there are already calls for draconian action against diesel vehicles in cities. In November, London's mayor Sadiq Khan called for a scrappage scheme and taxes to encourage a switch ●



SLOW DOWN

But at levels 7 to 9, people with these conditions and the elderly are advised to cut back on such activity – as should anyone getting sore eyes, a cough or sore throat. At very high levels, the at-risk groups should avoid all strenuous activity, while everyone else should cut back on physical exertion, such as cycling.

PLAN YOUR ROUTE

Pollution levels vary from road to road, so planning your route can potentially lessen your exposure to airborne nasties. Londoners can head to the NHS's [breathelondon.org](https://www.breathelondon.org) and use the hourly updated air pollution map to make sure they sidestep the smog.



DEATHS FROM AIR POLLUTION IN YOUR REGION

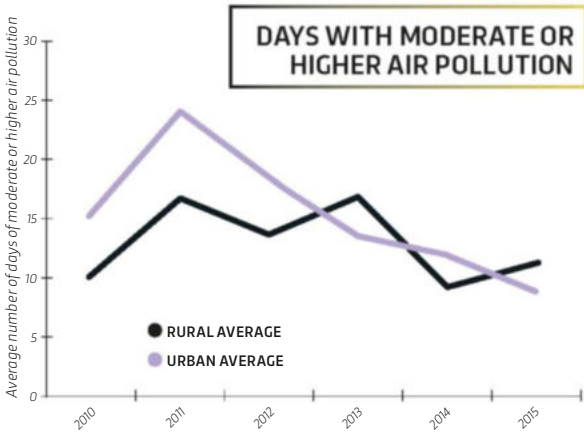
On this map, you can see the estimated percentages of adult deaths attributable to particulate air pollution*

8.3% 2.4%

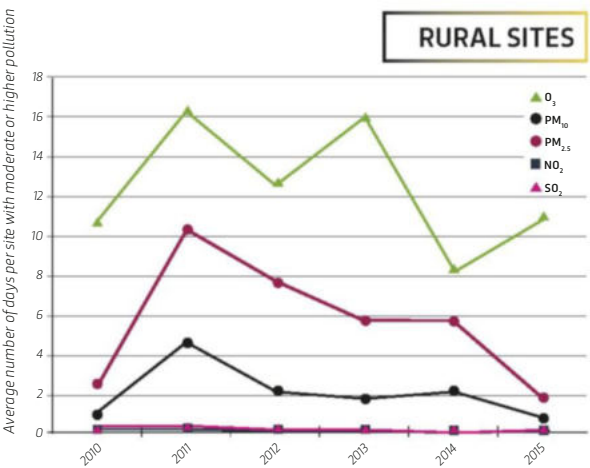


*Data on this map does not include deaths from other forms of air pollution

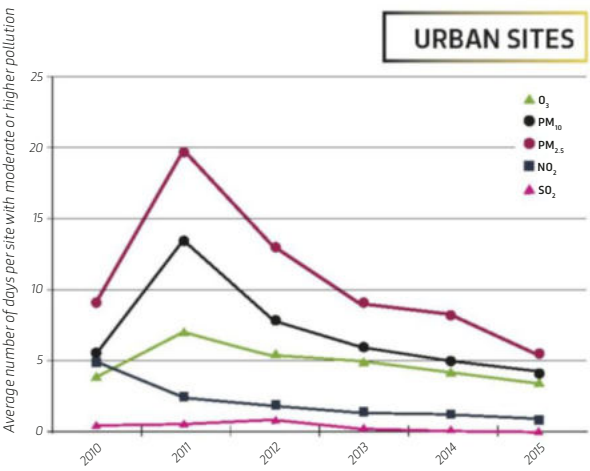
Levels of air pollution are declining, but experts are concerned it's not falling as quickly as expected



Over the course of five years, between 2010 and 2015, air pollution was monitored at rural and urban sites across the UK to generate this graph.



At rural sites, ozone (O₃) is the main cause of pollution on days with moderate or higher pollution levels. Sulphur dioxide (SO₂) and nitrogen dioxide (NO₂) barely contribute to rural pollution.



At urban sites, particulate matter (PM₁₀ and PM_{2.5}) were the main cause of pollution on days with moderate or higher pollution.

“EVEN TRAFFIC CONTROL MEASURES LIKE SPEED BUMPS CAN AFFECT AIR QUALITY”

● to cleaner forms of transport. From 2020, London will impose charges on vehicles entering a new Ultra Low Emission Zone that fail to meet tight emission standards. Meanwhile, a network of displays giving air quality alerts is already being rolled out across London's bus routes, underground lines and major roads.

Other cities are going further, with diesel vehicles set to be banned from Paris, Madrid, Athens and Mexico City by 2025 under plans unveiled at a gathering of city leaders in December. But questions are already being asked about the effectiveness of such bans. A study of the impact of London's existing low-emission zone found that three years after it was set up, there was still no

sign of improvement in either air quality or the respiratory health of children.

There is also concern about a problem that has long dogged attempts to solve environmental problems: unintended consequences. Experts caution that banning vehicles from driving through city centres can simply shift the problem elsewhere – including into residential zones, where most people spend the majority of their time, and kids go to school.

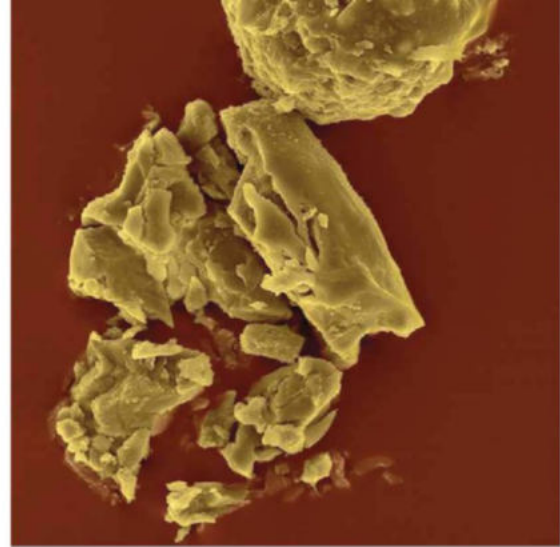
Other measures for tackling pollution have run into similar problems. Tree-planting has long been regarded as an ideal solution to air quality along roads. Research suggests that trees can mop up oxides of nitrogen, while a recent report by The Nature Conservancy

claimed that trees can absorb as much as 24 per cent of the particulate matter around them. But studies have also shown that trees give off their own pollution in the form of volatile organic compounds (VOCs). These can boost levels of ozone in the air and combine with other forms of pollution to affect vulnerable people, such as asthmatics.

The recent report by NICE went further, stating that trees can also slow air currents that would otherwise shift pollution: “It is not always true that trees reduce air pollution. Their effect is dependent on factors including species, canopy density, time of year and wind direction,” the report stated.

NICE also made headlines by pointing out that even traffic control measures like speed bumps can affect air quality, with vehicles accelerating after crossing them, releasing a cloud of pollutants.

Encouraging people to use their cars less could trigger unintended consequences. “Switching your urban commute from car to cycle will reduce overall emissions but probably increase your



ABOVE: Emissions from diesel vehicles contain large amounts of particulates, which are hazardous to lungs

personal exposure to traffic pollution,” says Prof Richard Skeffington, an air pollution expert from the University of Reading.

CLEANER CARS

Many believe the only effective answer is the outlawing of diesel in favour of cleaner technology such as electric motors. Environmental pressure group Greenpeace is campaigning to get the UK government to ban sales of diesel cars in the UK.

But experts caution that this is no panacea, either. According to the Royal Colleges report, recent research has revealed a new source of road pollution: particles rich in toxic metals shed by brakes, tyres and road surfaces. “Even electric and alternatively fuelled vehicles can never be emission-free,” say the report's authors.

The issue of air pollution may yet become a case study of the dangers of simple solutions to complex problems. Ironically, it was environmental concerns that sparked the surge in popularity of diesel engines in the first place. As they use fuel more efficiently, diesel engines emit less carbon dioxide than their petrol counterparts. Politicians keen to cut greenhouse gas emissions offered taxpayers incentives to buy diesel cars, whose numbers soared from 1 in 12 EU registrations in 1990 to over 50 per cent in 2010.

The adoption of diesel cars has had no measurable change in global warming – but air quality in cities across Europe has plunged. “Diesel engines are not the same as they were 20 years ago – they're probably better,” says Frew. “But there are always unintended consequences, and we don't know what we don't know.”

Prof Robert Matthews is a science writer and visiting professor in science at Aston University.

DISCOVER MORE



Read about how air pollution affects us, and watch a clip from *Trust Me, I'm A Doctor* at bbc.in/2jZkjfz

WATER

IS THIS MONTH'S TOPIC
IN THE BBC'S TERRIFIC
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**WATER WORLD**

Many of us are lucky enough to have water available at the turn of a tap, so it's easy to forget just what an unusual substance it is. Nevertheless, our existence – and all life on Earth – is exquisitely entwined with this marvellous little molecule.



UNDERSTAND WATER

It's one of the strangest substances in the Universe, but we wouldn't exist without it. Welcome to the wonderful world of water...

WORDS: BRIAN CLEGG

When Earth is seen from the depths of space it appears as a blue dot. This is because just over 70 per cent of its surface is covered with water. Water is present on many of the planets too, and several moons of Jupiter and Saturn are thought to have significant water resources. But Earth is, without doubt, the one body in our Solar System where water has a defining presence. It's thanks to water and its physical peculiarities that life has flourished in the first place. Water is so familiar to us that we often forget just what a remarkable substance it is.

What exactly is water?

Water is H_2O , a simple molecule consisting of two atoms of hydrogen and one of oxygen. It is the only substance that exists as solid, liquid and gas in the temperature ranges found naturally on Earth. Water is transparent, but isn't entirely colourless. Just as the sky is blue because molecules in the atmosphere scatter blue light more than other colours, so large quantities of water have a similar blue tinge, whether it's the ocean or the dramatic blues of glacier ice (oceans and lakes also reflect a blue sky, making them appear even bluer). We are extremely lucky to have so much water on Earth because it has remarkable properties.

What's so special about it?

Water is an impressive solvent, which means it is extremely good at dissolving things. This is partly why it's so valuable for living organisms, acting as a transport fluid for a whole host of chemicals in living cells. What

makes water such a good solvent is its ability to stick onto and separate the atoms of a substance, which is thanks to unusually strong hydrogen bonding. This is the effect that makes water so special: an electrical attraction between hydrogen atoms and other atoms such as nitrogen, oxygen, and fluorine. Hydrogen bonding *between* water molecules also makes them hard to separate, pushing up the boiling point. Without this effect, water would boil at around $-70^{\circ}C$. That would mean no liquid water on Earth – and no life.

Another essential side effect of hydrogen bonding is that when water freezes, the hydrogen bonds between the molecules pull the crystals into a

particular shape. This is why snowflakes form with six points, and it means that water crystals have more space in them than they otherwise would. They form tetrahedrons – shapes with four triangular sides. As a result, solid water, or ice, is less dense than the liquid form, which is why it's not recommended to put a glass bottle of water in the freezer (the water will expand and can shatter the bottle), and why ice floats on a pond.

It's often said that this property of water is unique. This is not quite true, as acetic acid and silicon, for example, are both less dense as a solid than as a liquid. But it *is* unusual, and it's important. If ice were denser than



Unlike most substances, water is less dense in its solid form than its liquid form

Artist's impression of a water vapour plume on Europa, one of Jupiter's moons



❖ water, lakes would freeze from the bottom, not the top, making it far less likely that aquatic life could survive cold winters.

Where in the Universe have we found water?

The chemical elements making up water (hydrogen and oxygen) are plentiful in the Universe. In fact, they're the first and third most common by mass. Therefore, it's not surprising that water shows up in many places. Every planet in the Solar System has at least some water, though the furnace-like Venus only has tiny amounts of vapour in its atmosphere.

Similarly, some moons are well-provided. Our own Moon appears to have ice deposits, while a number of the moons of Jupiter and Saturn, such as Europa, Ganymede, Callisto and Enceladus, are thought to have salty liquid water under surface ice. Comets, which plunge towards the Sun from the outer Solar System, usually contain large amounts of water ice. Further out, we find water in vast clouds of material between the stars, in the atmosphere of planets in distant solar systems and in the rotating discs of matter where new stars are forming. Water is indeed common, though rarely as dominant as it is on Earth.

How do we know there's water out there?

We can hardly go out to distant star systems and check for water, but astronomers have tried and tested methods to detect molecules in space. These rely on spectroscopy, or the study of the spectrum of light. When light passes through a material, some of the wavelengths of light get absorbed, leaving dark lines on the spectrum.

Spectroscopy was first used in astronomy to detect elements in stars, but it is now widely used when light passes through, say, a cloud of matter in deep space.

Different compounds have their own distinct 'absorption spectra', like a fingerprint for a specific molecule. There are even distinctions, for example, between the spectra of liquid water and water vapour (though as yet we can't detect liquid water on a planet unless we can observe it directly).

Detecting water vapour in the atmosphere of a planet orbiting a distant star is more difficult than detecting standalone water molecules in space, because the signal is harder to distinguish from the star's own spectrum. However, a new technique being trialled by the European HotMol project combines spectroscopy with information about the light's ❖

JARGON BUSTER

ELECTROLYSIS

The process of passing electricity through a fluid, which will attract positively charged ions to one electrode and negatively charged ions to the other.

HYDROGEN BOND

An attraction between the relative positive electrical charge of a hydrogen atom and the relative negative charge on an atom like oxygen, making it harder to separate water molecules than we'd expect.

IONS

Atoms are electrically neutral, with the same number of negative electrons and positive protons, but can either lose or gain electrons. When they do, they're called ions.

POLARISATION

Light waves wiggle from side to side as the light moves forward. If these movements are all in the same direction then the light is said to be polarised, which affects the way it interacts with matter.

RELATIVE ELECTRICAL CHARGE

Although atoms are electrically neutral, when hydrogen and oxygen connect in water, the position of the electrons shifts, giving the atoms an effective charge.

SPECTROSCOPY

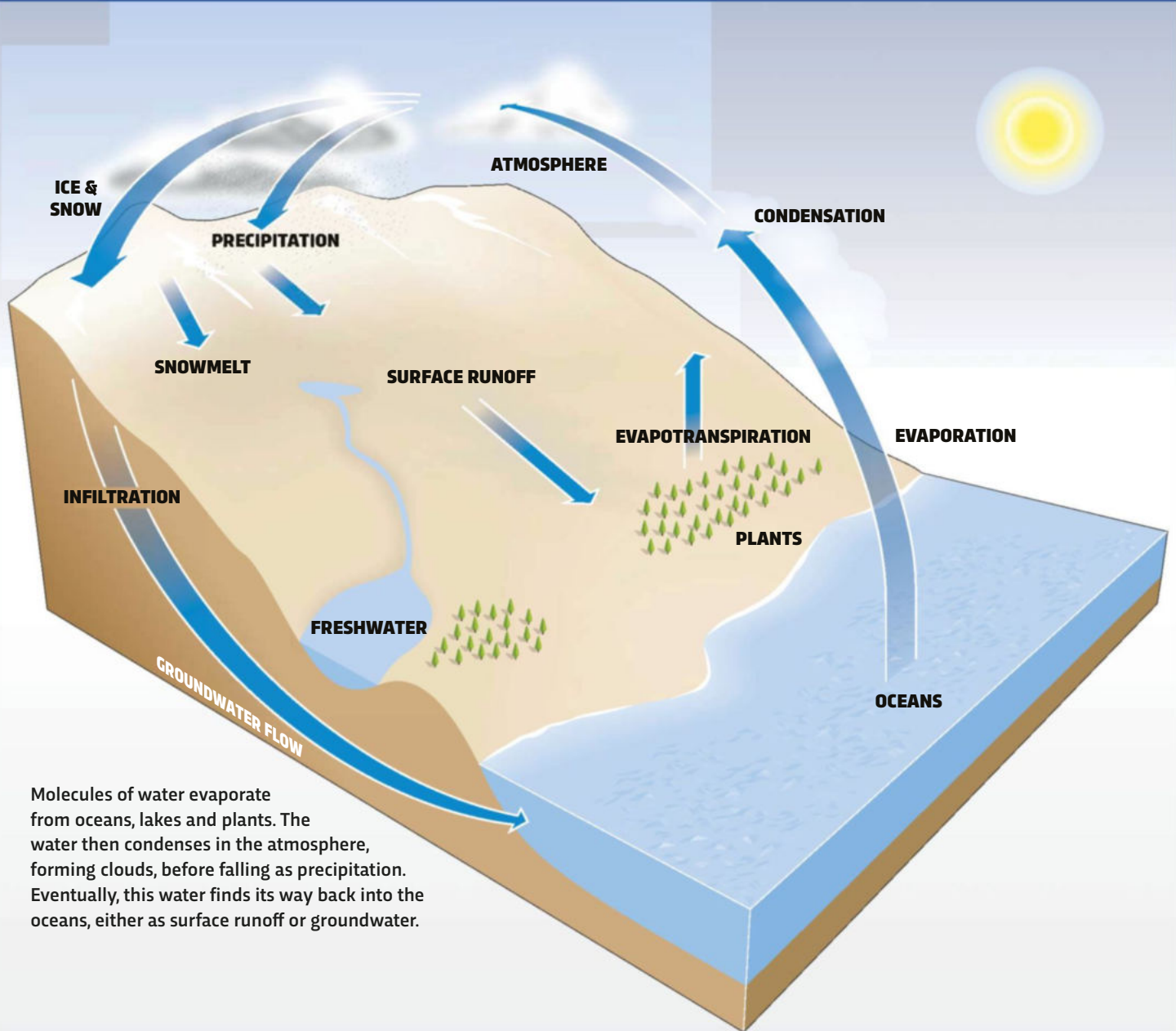
When light hits an atom, some is absorbed by the atom's electrons. Each element has specific frequencies it absorbs, which show up as dark lines in a white light spectrum when light shines through it.



Glacier ice is blue in colour because of light scattering

THE WATER CYCLE

Earth's water is always in motion...



Molecules of water evaporate from oceans, lakes and plants. The water then condenses in the atmosphere, forming clouds, before falling as precipitation. Eventually, this water finds its way back into the oceans, either as surface runoff or groundwater.

WHAT WE STILL DON'T KNOW

1 DOES LIFE EXIST WITHOUT WATER?

All life on Earth needs water. But it is possible that there could be life elsewhere that uses different mechanisms and chemistry. For example, Saturn's largest moon, Titan, has oceans of liquid methane and ethane, which could provide the liquid base for a different type of life. Even so, we continue to use water as a marker for the possibility of life, as this is currently our best guess.

2 HOW MANY TYPES OF ICE ARE THERE?

Ice has many crystal forms – we aren't sure how many in total. Novelist Kurt Vonnegut dreamed up 'ice-nine', a special form which would solidify at room temperature and could turn the oceans solid. Luckily, this doesn't exist, but there do seem to be at least 18 different solid 'phases' of ice where crystals have different structures and shapes. In 2016 it was discovered that even liquid water has two different states, changing behaviour at around 50°C.

3 WHY DOES WARM WATER FREEZE FASTER THAN COLD WATER?

Although observed for centuries, the idea that warm water freezes quicker than cold water is called the Mpemba effect after the Tanzanian schoolboy Erasto Mpemba who studied it in the 1960s. Suggestions have been made for why it occurs, but pinning down an explanation appears to be hampered by the difficulty of making two identical samples and of establishing exactly when a sample has frozen.



In one tweet...

Water is essential for all known life – its special structure means it floats as a solid, is a great solvent and is liquid at room temp.

• polarisation, which may give an indication of the spectrum's source. Technology is increasingly making it possible to discover just how widespread water is in the Universe.

Is water essential for life?

Water is certainly essential to the forms of life we have on Earth, which all have a common ancestry and require water to function. Life has been found in all kinds of extreme environments, operating at the limits of heat and cold and even without air. But every type of life we have discovered contains biological cells that require water to provide their operating environment. Cells simply could not function without it. It's not just a matter of keeping them inflated and moving chemicals around – living cells are full of tiny complex mechanisms. Many of these mechanisms rely on different sections of molecules either working well with water, or not mixing with it. Proteins, for example, are the key worker molecules in living organisms. Proteins have to fold into particular shapes to carry out their roles, and it is the interaction with water by various parts of a protein molecule that tell it how to fold. Water isn't just a solvent: it is intimately involved in the functioning of our magnificent cellular machinery.

How much water do we have in our bodies?

We humans contain a large amount of water, typically between 50 and 70 per cent by weight. The majority of this is in the approximately 30 trillion cells that make up the body, while the rest is in fluids such as blood.

In our cells, water prevents the cell from collapsing and also acts as a medium for various molecules to get from place to place. This transport role is more obvious where the water is moving, such as carrying material around the bloodstream. It also lubricates, dissolves valuable chemicals, and acts as a shock absorber for organs. It's hard to find a part of the body where water doesn't play a role – even bones are around one-third



Water doesn't just satiate our thirst, it also plays an essential role in the functioning of our cells

water. Incidentally, although we do need about two litres (eight glasses) of water a day, we don't need to drink it in its pure form, as other drinks can hydrate us too. Plus, we typically get around half our liquid requirements from water in food.

How did the Earth's water get there?

Although we're not 100 per cent certain of the origin of the Earth's water, it's generally thought to be a combination of water from the cloud of matter that initially formed the Earth, along with additional water from bodies that collided with the planet later. Being relatively close to the Sun, our planet would have lost some of its initial water during its formation, but bodies that are further out, such as asteroids and

comets, were more likely to hold onto their water and could have added to the Earth's supplies when the Sun's gravitational pull brought them towards us.

For a long time, it was thought that a high percentage of the Earth's water came from these later additions, but recent research shows that water on most comets and asteroids tends to contain more deuterium – a hydrogen isotope – than water on Earth does. This suggests that a lot of the water on our planet dates back to the origin of the Solar System and that much of it might have been protected in the Earth's early days by remaining well below the surface. Only last year it was discovered that rocks at depths of up to 1,000 kilometres could store water.

1 BLUE PLANET

Earth's defining feature is water – it's what makes the planet look blue from space. But there's water on many of the planets and out in space. Water is a simple chemical compound of hydrogen and oxygen in the ratio 2:1, but it can do amazing things.

2 STRONG BONDS

What makes water special is hydrogen bonding. This electrical attraction between its molecules vastly increases its boiling point and makes it less dense as a solid than as a liquid. Without hydrogen bonding there would be no life on Earth, as water would boil at around -70°C.

3 THE FONT OF LIFE

Living things use water as a lubricant and a solvent, carrying a whole range of chemicals around their cells, as well as keeping those cells in shape and making tiny molecular machines function. It's possible that other liquids could play the same role, but water is ideal.

BELOW:
Desalin ion
plants, like
this one in
Spain,
remove
salt from
seawater to
make it
drinkable

How does the water cycle work?

Thanks to the Sun's constant stream of energy, water molecules are continually evaporating as water vapour from the surfaces of oceans and lakes (as well as plants and soil), adding to the water vapour in the air. This is carried by winds around the planet. Where the vapour reaches particularly cold air, and has particles to condense around, it forms the tiny water droplets that make up clouds, which combine to form larger drops and eventually fall as rain. When rain falls on high ground, it runs down as streams and rivers, eventually feeding back into the oceans. This cycle is essential for the many living things that otherwise live on dry land.

Why do we have to save water when there's so much of it?

One thing is definite. As a planet, we aren't short of water. Over 70 per cent of the Earth's surface is water – 1.4 billion cubic kilometres of the stuff. This is such a huge amount, it's difficult to visualise. A cubic kilometre is a trillion litres of water. Divide the amount of water in the world by the number of people and we end up with 0.2 cubic kilometres of water each. With a reasonable consumption of five litres


A water molecule consists of one oxygen atom and two hydrogen atoms



per person per day, the water in the world would last for 116,219,178 years. And that assumes that we use up the water. In practice, the water we 'consume' soon becomes available again for future use. Water shortages are really energy shortages – it's the cost of energy that makes it difficult to provide usable water. The problem is that water is either in the wrong place, so needs moving, or needs something removing to make it drinkable – and nowhere is this more obvious than with seawater.

Why is it so difficult to convert seawater into drinking water?

Living in the UK, surrounded by ocean, it can seem absurd that we ever experience water shortages. The same applies to many countries with coastlines. And it is perfectly possible to convert seawater to drinking water. It's simply an expensive and energy-intensive process.

Seawater typically contains around 3.5 per cent minerals by weight, mostly the sodium and chloride ions that form salt when the water is evaporated. The easiest way to make this drinkable is simply to boil the water and collect the pure vapour. Alternatively, hydrogen and oxygen can be separated from the seawater by electrolysis and recombined to make water, or the minerals can be removed by special membranes which only allow some molecules through. Practical desalination plants tend to use variants on the evaporation technique: the process isn't difficult, it's just that it takes a great deal of energy to remove the impurities, usually significantly less energy than is required to get water from other sources such as the ground or recycling. 

Brian Clegg is a science writer. His most recent book is *Are Numbers Real?* (£12.99, Robinson).

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HELEN CZERSKI... **HOW DO LEDS WORK?**

"THOSE BICYCLE LIGHTS HAVE BEEN FLASHING AWAY FOR YEARS, AND I'VE NEVER NOTICED"

To be honest, I should have been better prepared. But I'd bounced out of my flat in the morning without checking the weather forecast and at 6pm, I was cursing my optimism. Torrential rain was pouring out of the dark sky, and I was wearing jeans, on a bike, without a proper raincoat. The slots in my cycling helmet were funnelling water down the back of my neck, and I was cold. I tried telling myself that Scott had faced far worse on his way to the South Pole, but the novelty of that ran out after about 30 seconds, leaving the remaining 20 minutes of my cycle filled with grumpiness. And every single traffic light seemed to be on red. Halfway home, I was squinting out through the small waterfall taking shape over my face, and became distracted by the rain in front of me. The blackness just beyond my handlebars was shot through by dashed white straight lines, with spaces exactly the same length as each dash. At the next red traffic light, it was the same: a strictly regimented pattern in the messy fluid chaos around me. My bike lights were clearly flashing, but too fast for me to see.

I reckoned that each dash and each gap was about a centimetre long, and the rain was pretty heavy so the average raindrop speed was probably about 5m/s. That gives a flashing rate of about 250 times each second, or 250Hz. Why would my bike lights be flashing like that?

When I got home, and after one of the most welcome hot showers I've had in a long time, I took a closer look at my lights. They're LED ones, compact but astonishingly bright. They've got two brightness settings, and my front light had been on 'half



brightness', which is still shockingly intense.

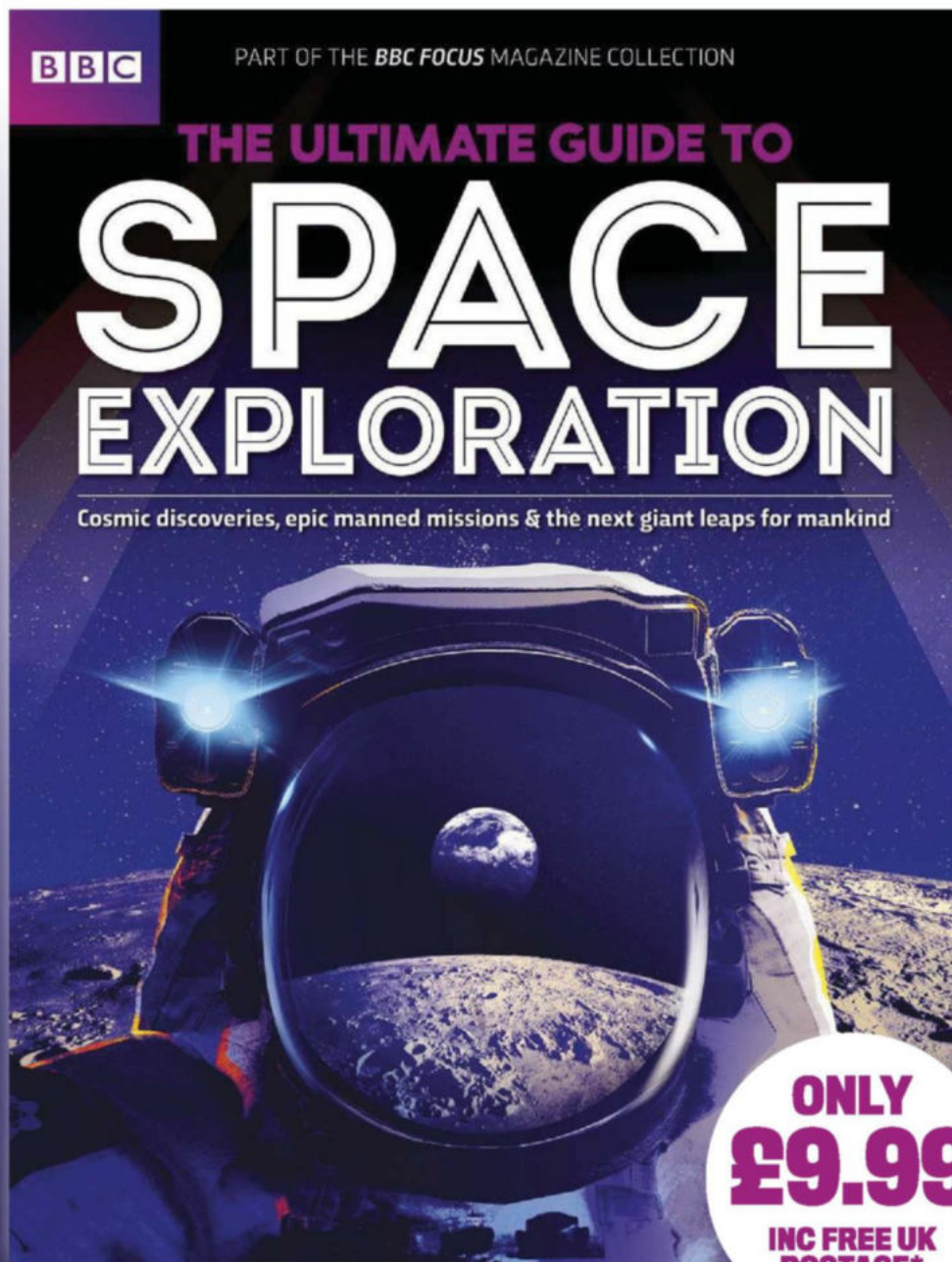
When you use a dimmer switch at home, you're normally controlling the voltage to the light bulb. But this is a rubbish way of dimming an LED light. LEDs (light-emitting diodes) work by having two materials next to each other, one with some extra electrons and one with some extra holes where electrons could go. If you push an electric current through the junction, you effectively shove the electrons until they fall into the holes, and the extra energy left over from that process is emitted as light. But in this system, even a tiny difference in voltage causes a huge difference in current (and light), making it tricky to regulate the brightness by altering the voltage. So what manufacturers do is to pulse the current – the level of current stays fixed but it's switched on and off hundreds of times each second. A human

won't detect any flicker in the light as long as the pulse rate is up above about 300 cycles per second, so my estimate of 250 flashes wasn't bad. To dim the lights, the number of flashes per second stays the same, but the pulse itself gets shorter and the gap gets longer. It's called 'pulse width modulation dimming', and it's used everywhere you find LEDs with a dimming option.

What's fascinating about all this is that those lights have been flashing away for years, and I've never noticed. It was only when a single falling raindrop was illuminated several times on its way down that the flashes became visible. Such a low-tech way of spotting a very high-tech solution... almost (but not quite) worth getting soaked to the skin for! **Q**

Dr Helen Czerski is a physicist and BBC science presenter. Her book, *The Storm In A Teacup*, is out now (£8.99, Transworld).

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Physicist,
science writer

YOUR QUESTIONS ANSWERED

MARCH 2017

EDITED BY EMMA BAYLEY



Fire retardant is dropped near Clearlake, California, during the wildfires of August 2015

How effective are planes in fighting wildfires?

ROSALIND PATTERSON, US

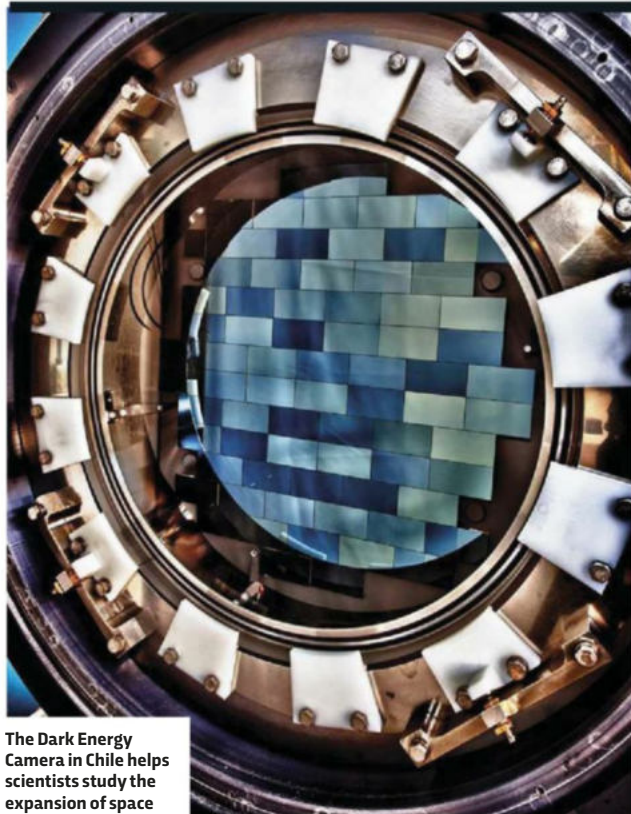
The US Forest Service has commercial contracts for a fleet of 300 helicopters and more than 50 fixed-wing aeroplanes, which dump 40 million litres of fire-retardant sludge onto forest fires each year. But surprisingly there isn't very good evidence that it works. A 2011 study found no correlation between the use of fire retardant and fire-fighting success rates. Once a wildfire is raging, airdrops seem to be more about public relations than effective firefighting. **LV**



Does sucking your thumb really ruin your teeth?

LES REEVES, LONDON

Sucking a thumb or dummy up to the age of two is fine, but several studies have shown that beyond that, there is a risk that the front teeth can be pushed outward, or the side teeth shifted so that the top and bottom sets don't meet. A 2001 study by the American Dental Association found that about 20 per cent of children who suck their thumb beyond the age of four have a misaligned bite. **LV**



The Dark Energy Camera in Chile helps scientists study the expansion of space

Can a computer generate a truly random number?

KEN REHILL, CANADA

Computers are often required to produce random numbers as they're useful for a host of tasks, from taking random samples of data to simulating the formation of galaxies. But computers produce these numbers using mathematical formulas, which means they aren't truly random. This isn't as bad as it seems, as true randomness is prone to producing bizarre patterns that can fool researchers into seeing effects that don't exist. To avoid this, the so-called pseudo-random number generator (PRNGs) formulas used in computers undergo statistical tests to keep the risk of long 'runs' below a certain threshold. Even so, some computer-generated random numbers have still caused problems. Subtle patterns in the output of the so-called RANDU generator created by IBM in the 1960s is suspected to have undermined the reliability of many research projects over the years. **RM**

What is dark energy?

FRED THOMAS, LONDON

During the 1990s, astronomers measuring the rate at which the Universe is expanding made a shock discovery: it's actually accelerating, as if the whole cosmos is being propelled by some invisible source of energy. This is so-called dark energy and its origin is one of the deepest mysteries in science. Various explanations have been put forward, with arguably the simplest being that it's a manifestation of so-called quantum vacuum processes. According to the laws of the subatomic world, there is always some uncertainty about the amount of energy filling even empty space. This vacuum fluctuation energy has been detected in the lab, and theorists have shown it can have the 'anti-gravitational' effects of dark matter. So far, however, they have struggled to produce a detailed theory of its cosmic effects.

This has led to suggestions that dark energy may simply be a force-field left over from the Big Bang. Sometimes called quintessence, it's capable of getting stronger over time, but again details remain elusive. There have even been claims that dark energy is leaking out from hidden extra dimensions of space that failed to expand following the Big Bang. Until there's a breakthrough in the underlying theory, however, all this is little more than speculation. **RM**



Archaeopteryx was an animal that shared features of both dinosaurs and modern birds

QUESTION OF THE MONTH

Why didn't dinosaurs evolve to be more intelligent?

STEVE BARRON, NORTHUMBERLAND

WINNER!

Steve Barron wins a set of VerveRider+ wireless and waterproof headphones (£79.99, verve.life). The comfortable collar design means you'll almost forget you're wearing them.

They did! Dinosaurs evolved into modern birds and some of them are extremely intelligent. In Japan, there are crows that have learnt to use the traffic to crack the shells of nuts that they drop – and they will wait for the lights to turn red, so they can safely retrieve them.

One reason that birds still aren't as intelligent as humans is that a heavy, energy-hungry brain doesn't mix well with birds' main adaptive advantage – flying. It's important to realise that intelligence isn't the goal of evolution, nor is it always the best adaptation to the environment.

The enormous sauropod dinosaurs lasted on the planet for 100 million years, despite their tiny brains. We've had 'intelligence' for just a few million years, so it's too early to say whether it is a better strategy. **LV**

THE THOUGHT EXPERIMENT

HOW COULD I SURVIVE BEING WASHED UP ON A DESERT ISLAND?



1. WATER

You can only survive three days without water. Scavenge the beach for containers and set each one in the sand, at the bottom of a wide, shallow pit. Line the sides with palm leaves, arranged so that rain drips into the bottles. While you wait for rain, explore the island to look for streams.



2. FOOD

Coconuts are a great food source. Wedge one on the ground, with the pointed end facing upwards. Find the largest rock you can lift and drop it onto the coconut to break the husk fibres apart. One survivor of the 2004 tsunami ate nothing but coconuts for 25 days before being rescued. So your chances are good!



3. SHELTER

Unless you can sleep, you will lose the ability to concentrate, plan and stay motivated after just one or two nights. A bundle of small branches spread on the ground and covered with palm leaves is still better than sleeping directly on the sand. After that, build a low bed frame by tying together saplings.



Do fish have an immune system?

RACHEL MORRIS, LEICESTER

Most fish have an immune system similar to other animals with backbones. They produce antibodies that detect and bind to substances invading the body, like viruses and bacteria, and instruct white blood cells to destroy them.

Just like in humans, it's possible to vaccinate a fish against future infections by exposing them to a less virulent strain of a disease-causing microbe. Fish also cover themselves in a layer of sticky mucus that traps microbes and contains antimicrobial chemicals. The more stressed a fish gets, the more infection-fighting goo it makes. **HS**

Why do wagon wheels sometimes seem to move slowly in old films?

ROBIN CHAMBERS, PRESTON

Films are shot as a series of individual frames taken at around 24 per second. If the wagon wheel is rotating at precisely the right rate, then a spoke in one frame will have been taken up by another spoke in the next frame, creating the impression the wheel is stationary. If they're slightly out of sync, however, the wheels will appear to move in slow motion. **RM**



IN NUMBERS

32

The percentage of amphibian species at risk of extinction. Threats are habitat loss, pollution, disease and climate change.

24,000

The number of years ago that humans first reached North America – 10,000 years earlier than previously thought.

47

The percentage of fish that was mislabelled in Los Angeles sushi restaurants, according to DNA tests.

PHOTOS: GETTY X4

TOP 10

10 OLDEST PLANTS ON THE PLANET*



1. Seagrass colony (*Posidonia oceanica*)

100,000 years old
Balearic Islands, Spain

2. 'Pando' Quaking aspen colony

80,000 years old
Fishlake National Forest, Utah

3. 'Jurupa Oak' Palmer's oak colony

13,000 years old
Jurupa Mountains, California

4. Mojave yucca

12,000 years old
Mojave Desert, California

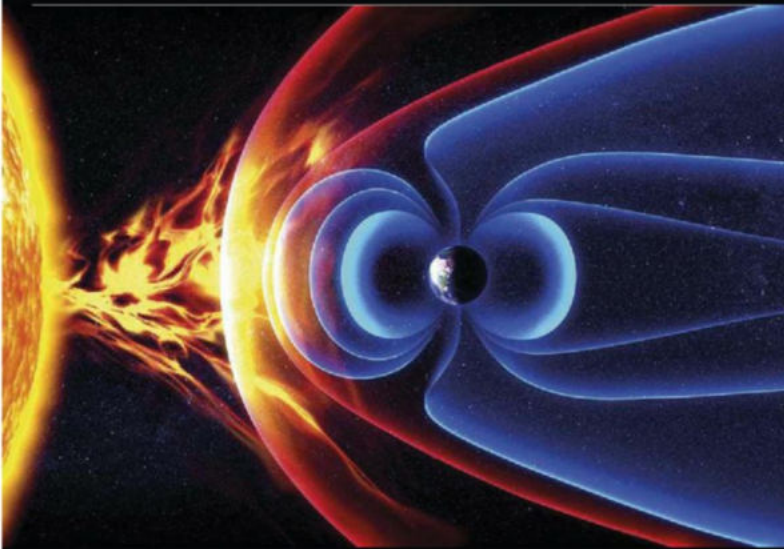
5. Huon pine colony

10,500 years old
Mount Reed, Tasmania

*Including clonal colonies with interconnected root systems, but discounting plants without reliably determined ages

Do all planets have magnetic fields?

DANIEL J BUHS, US



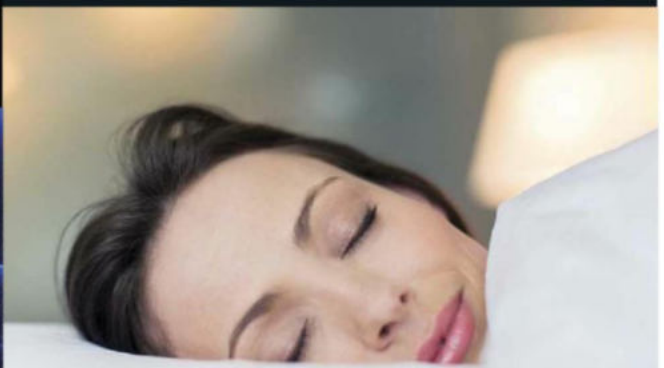
No, not all planets have magnetic fields. The four gas giants have extremely strong magnetic fields, Earth has a moderately strong magnetic field, Mercury has an extremely weak field, but Venus and Mars have almost no measurable fields. Planetary magnetic fields are formed by the interaction between the convection of interior conducting material (molten rock and metal) and the planet's own rotation. Mercury's field is weak because it rotates so slowly. Venus doesn't have an appreciable field because there appears to be little convection in its molten interior. Mars doesn't have an appreciable field – although it did in the past – because its interior has solidified. **AGU**

ILLUSTRATIONS: RAJA LOCKEY

How much sleep do we really need?

MARTIN MOORE, GLASGOW

The cliché is that we need eight hours a night, but the actual answer to this question is more complicated. Our sleep requirements change throughout life. Guidelines proposed by the National Sleep Foundation in 2015 recommended that newborns have 14 to 17 hours per night, teenagers have 8 to 10 hours, and adults have 7 to 9 hours. These guidelines focus largely on 'average' requirements, but individuals can differ greatly from one another. For example, it may be appropriate for certain teenagers to have as few as 7 hours per night, or as many as 11. If you're not functioning your best, it's worth considering whether you're getting enough sleep. **AGr**



6. 'Old Tjikko' Norway spruce

9,550 years old
Fulufjället Mountains, Sweden

7. 'Old Rasmus' Norway spruce

9,500 years old
Härjedalen, Sweden

8. Antarctic moss

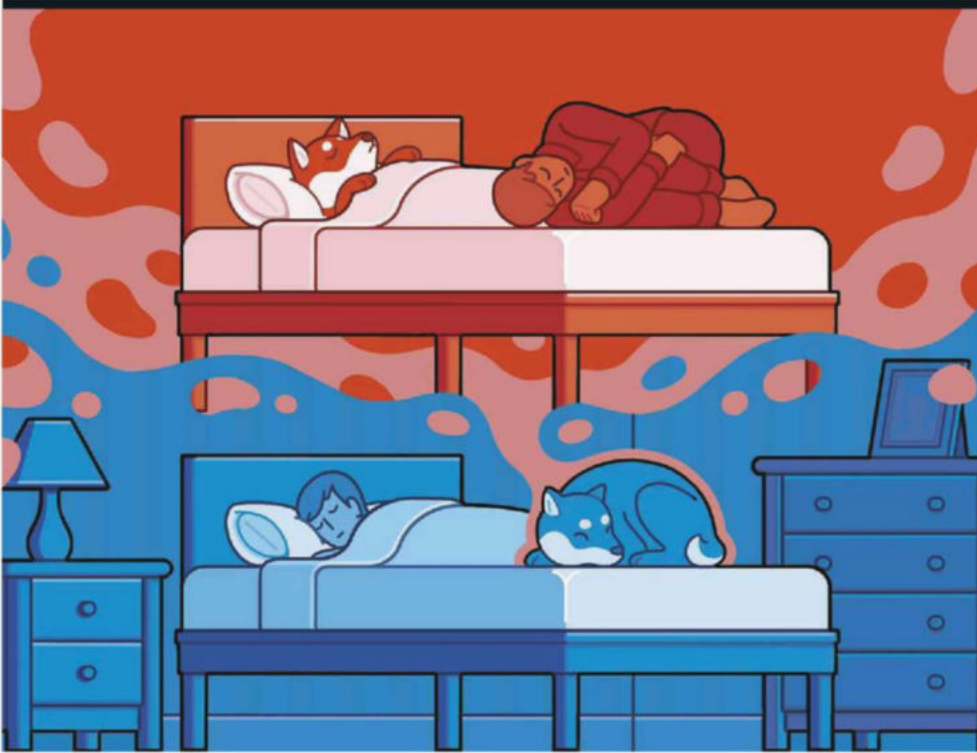
5,500 years old
Elephant Island, Antarctica

9. Bristlecone pine

5,066 years old
White Mountains, California

10. 'Methuselah' Bristlecone pine

4,848 years old
White Mountains, California



Do dogs have visual dreams?

HANNAH MAY LATHAN, OXFORD

Yes. In 2001, researchers at MIT monitored brain activity in rats as they solved a maze. They found that the animals showed the same brain activity patterns during sleep. The match was so close that the researchers could tell which part of the maze the rat was dreaming about. Cats and mice show similar results, so it is likely that visual dreams are common to all mammals, including dogs. **LV**

Why is the Moon colourless?

EDWARD SEYMOUR, HOVE

Despite appearances, the Moon is not entirely devoid of colour. Apollo astronauts described its colour as 'brownish'. Careful study shows that the dark areas, or 'maria', display hints of blue or brown while the highland areas have faint traces of yellow, pink and pale blue. These differences are mainly due to varying amounts of metals such as iron or titanium in the surface minerals.

Unfortunately, the human eye isn't sensitive enough to pick out these slight differences in colour from a distance. However, much of the lunar surface contains minerals that are naturally grey and these dominate the colour we perceive from Earth. **AGU**

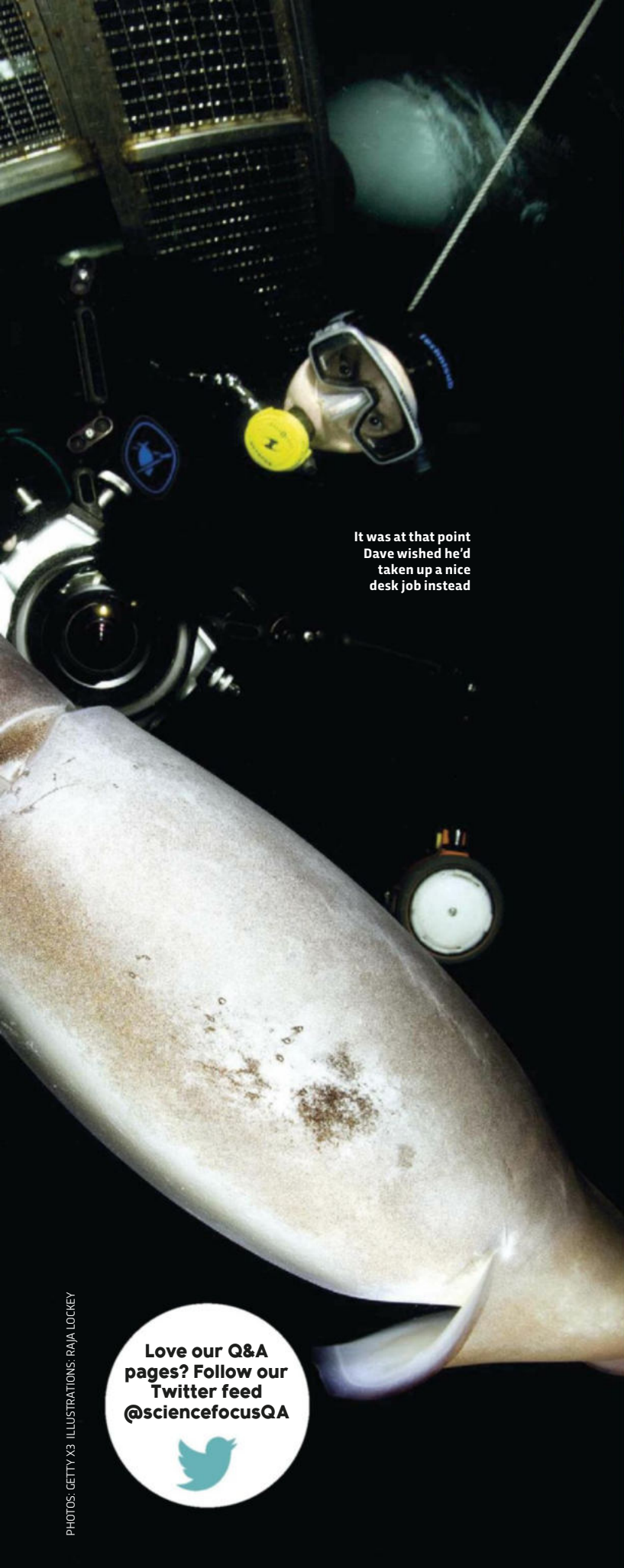


How do squid survive the extreme pressures of deep water?

ADAM STEPHENS, SALISBURY

A big challenge facing squid in the deep sea is keeping their cells working. Under high pressure, important molecules like proteins in cell membranes and enzymes become squashed and bent out of shape and either work more slowly or not at all. One way squid counteract this is by loading their bodies with trimethylamine oxide or TMAO, which helps large molecules keep their shape. For many deep sea animals, the deeper they live the more TMAO they have in their bodies. TMAO also gives rise to the distinctive fishy smell of many sea creatures – the deeper the species lives, the more it smells. **HS**



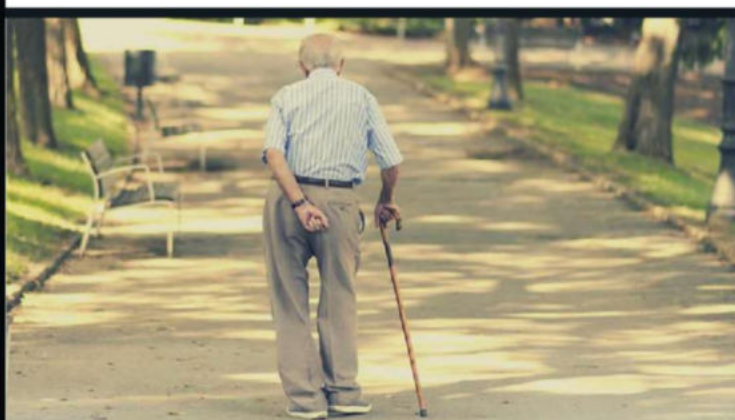


It was at that point
Dave wished he'd
taken up a nice
desk job instead

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PHOTOS: GETTY X3 ILLUSTRATIONS: RAJA LOCKEY



Why do we shrink as we age?

BEN PAGE MARTIN, NOTTINGHAM

The cartilage pads between the joints in your legs and spine gradually wear away as you get older, and osteoporosis can cause the vertebrae themselves to shrink slightly. You also lose muscle as you age and all of these factors mean your skeleton slumps down a little more. Between the age of 30 and 70, this adds up to about 3cm height loss for men and 5cm for women, increasing to 5cm and 8cm by age 80. **LV**



Is there acid snow (like acid rain)?

ALEX ROUND, LONDON

Acid snow is produced in exactly the same way as acid rain. It all starts when sulphur dioxide and nitrogen oxides are emitted into the atmosphere, typically by power stations burning fossil fuels. Inside clouds, these molecules react with tiny droplets of water to form sulphuric and nitric acids. The water eventually falls as drops of acid rain, or, if it is cold enough, ice crystals form and fall as acid snow. Acid snow can be particularly damaging since it can accumulate on the ground, before abruptly releasing a large quantity of acidic water into the environment when it melts. **AC**



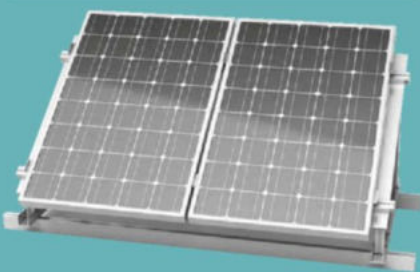
Why are fats solid at room temperature but oils liquid?

AYENSU ANKOMA APPIA, GHANA

To form a solid, molecules need to pack together nicely, while in a liquid there is less order and the molecules flow around each other. Fat molecules are mostly made up of long, straight hydrocarbon chains. Because they are straight they pack neatly with their neighbours (think of the way uncooked spaghetti packs together in a jar). Oils generally have chains which are kinked, this stops them interacting so tidily and so they stay liquid (imagine the storage problems you'd have if there was a bend in the middle of every piece of spaghetti). By definition, fatty molecules that form liquids are called oils and those that form solids are called fats. **ML**

Can solar panels be recycled?

AMY RHYS-DAVIES, CAMBRIDGE



Panels that convert solar energy into electricity last for decades, but when they do eventually wear out, they can be turned into new products – including fresh solar panels. Most of the materials they're made from, such as glass, aluminium and copper, has been recycled for years. The semiconductor materials in them, such as silicon and cadmium telluride, can virtually all be recovered by specialist companies. **RM**

WHAT CONNECTS...

...RATS AND LANDMINES?



1.

The giant pouched rat is a large African rodent, only distantly related to true rats. They can weigh up to 1.5kg and measure 45cm from nose to tail.

2.

Giant pouched rats are omnivorous, but they are particularly keen on bananas. They are also highly intelligent and can easily be tamed using a clicker, which they learn to associate with banana treats.



3.

They are much more than just pets though, because they can smell explosives at very low concentrations.

A Belgian NGO has so far trained more than 280 rats to sniff out TNT.



4.

The rats are used to detect landmines in Mozambique, Cambodia and Angola. A single rat can check 200m² in 20 minutes – something that would take a human four days to do!



Are fireworks bad for the environment?

STUART CHING, NOTTINGHAM

Fireworks propel a cocktail of chemicals into the atmosphere, many of which can harm both people and the environment. The vivid colours in firework displays come from metallic compounds such as barium or aluminium that can have negative impacts on animal and human health. Additionally, to produce the oxygen needed for an explosion, many

fireworks contain oxidisers known as perchlorates. These can dissolve in water, contaminating rivers, lakes and drinking water. Finally, fireworks release a fine cloud of smoke and particulate matter, affecting local air quality. Some newer, 'cleaner' fireworks replace perchlorates with safer alternatives, or use compressed air to reduce smoke created. **AC**



WHAT IS THIS?

What a gem!

This is an enormous cut topaz that weighs around 2kg. With a length of 15cm and a width of 10.5cm, it's the largest gemstone of its kind. It was discovered in its raw state in Brazil three decades ago, by the British explorer Max Ostro. Naturally, topaz is colourless, but impurities and differences in structure can give it a pale blue, red or yellow colour. To make the stones look more vivid, they are exposed to heat or radiation to enhance the colours, before being cut.

WHO REALLY DISCOVERED?

PENICILLIN

ALEXANDER
FLEMINGHOWARD
FLOREYERNST
CHAIN

It's one of the most famous stories in medical science: Scottish bacteriologist Alexander Fleming comes into his lab in London one day in 1928, and finds that bacteria on a test dish seem to have been wiped out by some mould that had landed in the dish. Fleming discovers the mould is secreting a compound he calls penicillin – it's the world's first antibiotic. Antibiotics have since saved countless people from deadly bacterial infections.

Yet Fleming himself was unconvinced penicillin could be turned into an effective treatment and lost interest in his discovery. Credit for turning a chance finding into one of the greatest medical breakthroughs ever should go to the Australian pathologist Howard Florey and the German-born biochemist Ernst Chain. During the late 1930s, they purified and stabilised penicillin, and in 1941 became the first to treat a patient. Despite a brief improvement, the patient died, as there wasn't enough of the wonder drug. This led Florey to cajole the giant US pharmaceutical companies into setting up mass-production facilities. By the D-Day landings of 1944 there was enough penicillin to treat thousands of injured troops who would otherwise have died. The following year, Fleming won the Nobel – along with Florey and Chain. **RM**



Can any plants live without sunlight in nature?

PRESTON SHUMACK, US

All plants can survive for short periods without light. Obviously, they need to be able to last through the night, but they can also cope with a longer darkness in an emergency. If you leave a tent pitched on the same patch of lawn, the grass underneath turns yellow and spindly. This is an adaptation, called etiolation, which focuses the plant's remaining resources into growing as far as possible to try and reach sunlight again. There are also some plants that have lost the power of photosynthesis altogether. The genus *Orobancha* (commonly known as 'broomrape') is an example. The plants have no

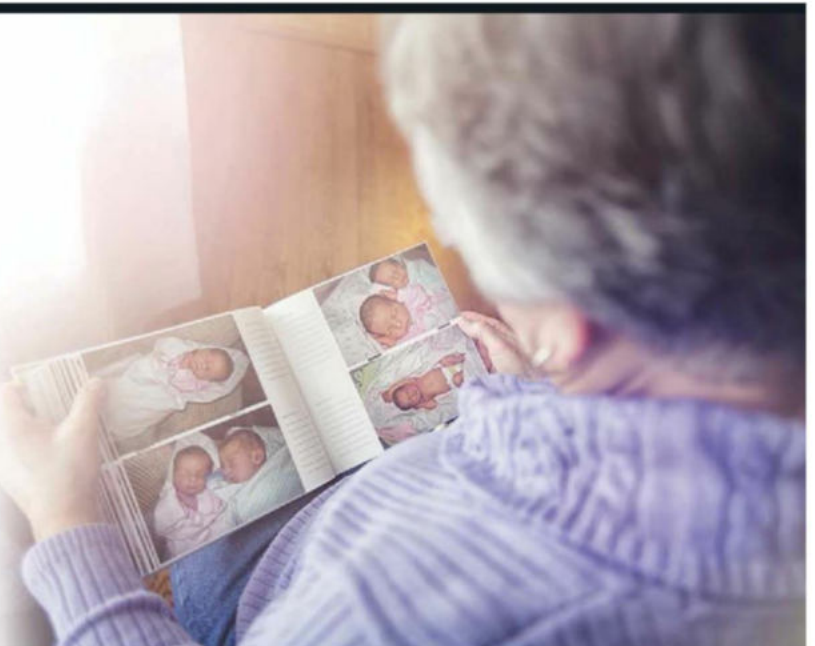
chlorophyll and get all their nutrients by parasitically attaching to the roots of nearby plants instead. Although broomrape doesn't harness sunlight itself, it is still indirectly reliant on the Sun to provide energy to its host plant.

Some other parasitic plants, called mycoheterotrophs, feed on fungi and these could theoretically survive in complete darkness for months or even years. But of course, those fungi in turn get their energy by digesting dead plants, and in a permanently dark world, this food source would eventually run out. No plant can live without sunlight forever. **LV**

Why do we forget things?

ALIREZA RIASATI, IRAN

Multiple explanations have been proposed. We may forget because we didn't store the memory effectively in the first place. It is also possible that memories decay over time. As they have not been revisited, their biological 'trace' becomes weak. Another theory suggests that new memories can interfere with older ones. Or that memories have been encoded and stored but that there is a problem with retrieval. Scientists sometimes refer to 'motivated forgetting' too, which involves forgetting an unwanted memory such as a trauma. This is controversial as there is also evidence that such unwanted events may be particularly difficult to forget. Forgetting is not always a bad thing! It would waste cognitive resources if we remembered every last detail of the world around us. **AGr**



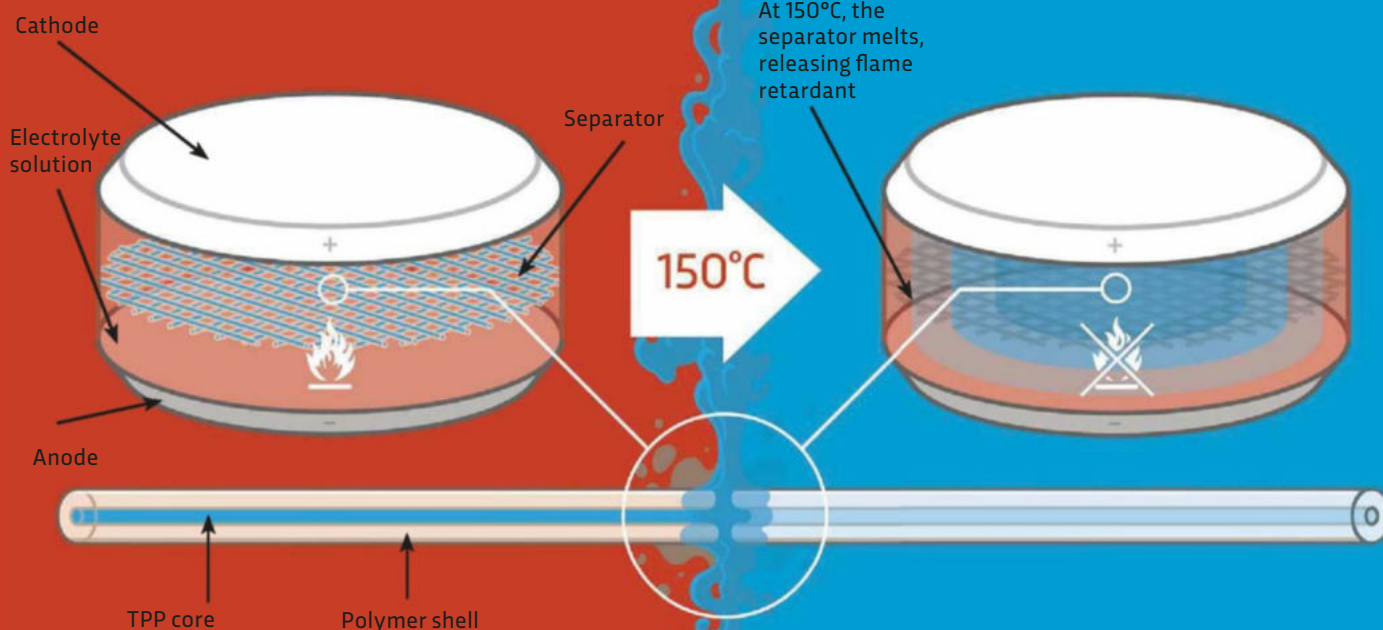
PHOTOS: GETTY X4, SCIENCE PHOTO LIBRARY

HOW IT WORKS

SELF-EXTINGUISHING LI-ION BATTERY

Lithium ion batteries contain a highly flammable electrolyte solution that allows ions to move from anode to cathode and back through a separator. However, if there is an internal short circuit, heat can build up, and the battery can potentially burst into flame.

Stanford researchers have developed a new separator made of polymer that contains triphenyl phosphate (TPP), which is flame retardant. If temperatures reach 150°C, the polymer shell melts, releasing the TPP to prevent combustion.



Can you have a shock wave in space?

DAVE GURLING, BILLERICAY

A 'shock wave' is the disturbance of material that's created when a wave moves through a medium at greater than the local speed of sound. Provided there is a 'medium' of sufficient density through which a shock wave can travel, there is no reason why shock waves can't form in space. However, because most environments in space are of extremely low density, traditional shock waves involving the collision of particles, such as those that give rise to a 'sonic boom', are rare. But there are other kinds of shock waves that can occur in low-density environments. For example, the shock can be propagated by photons interacting with electrons, by a

distribution of high energy particles or by magnetic effects. So, shock waves are actually quite common in space. Interplanetary shock waves can occur due to solar flares. 'Bow shocks' are formed by the interaction of the solar wind with planetary magnetospheres. Supernovae create powerful shocks, both within the star collapsing to form the explosion and also moving through the interstellar medium itself. Interstellar shocks can also occur simply by the collision or collapse of gas clouds. Black holes, high-density objects such as pulsars, as well as merging galaxies (and even just the motion of galaxies themselves) are also known to form shock waves of various forms. **AGu**



NEXT ISSUE:

What's the dodo's closest relative?

Is the flag still on the Moon?

Why can't we remember early life?

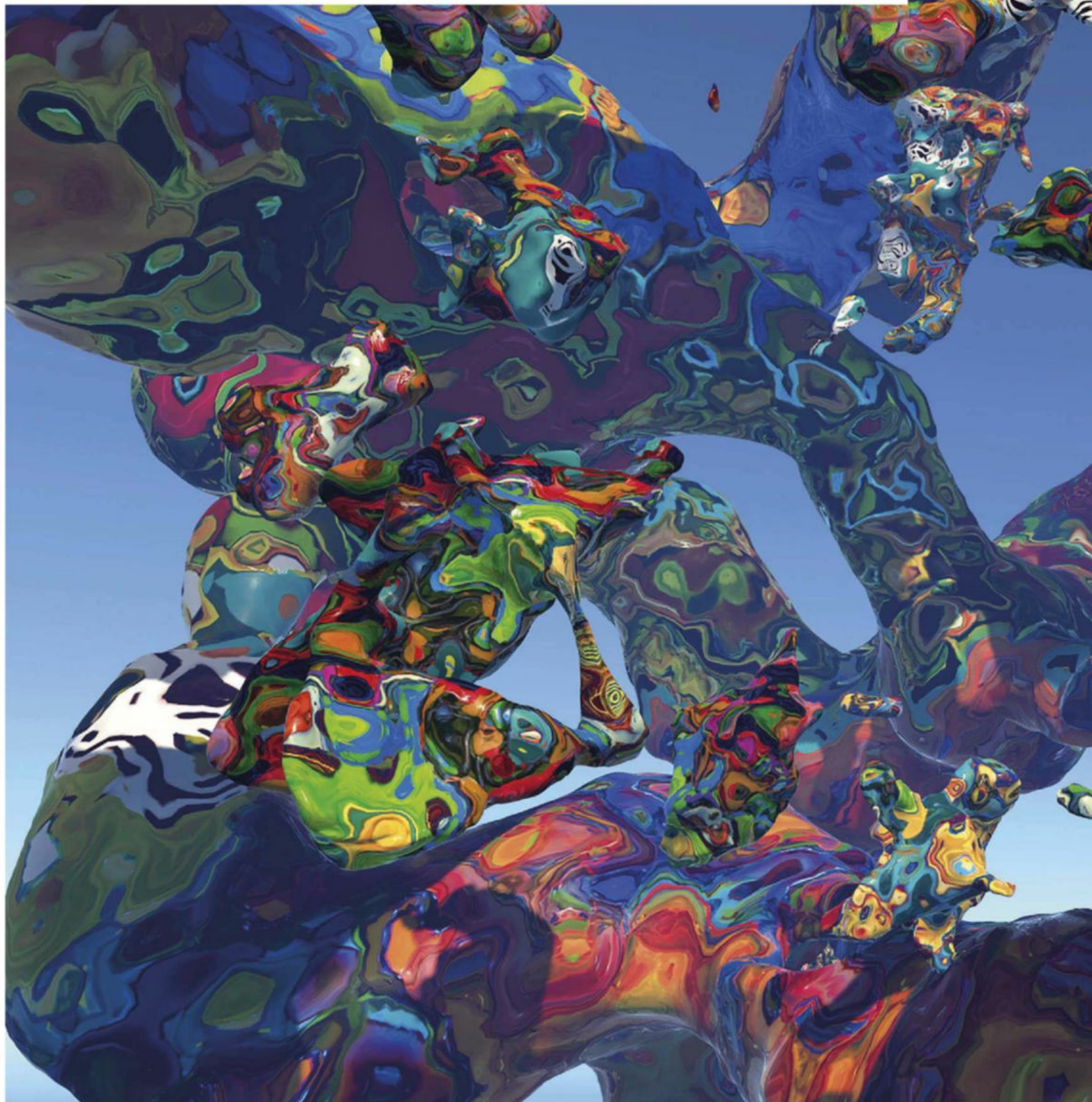
Email your questions to questions@sciencefocus.com or submit online at sciencefocus.com/qanda

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

MARCH 2017

EDITED BY JAMES LLOYD





01

VIRTUAL REALITY SHOW
LONDON, 20-22 APRIL 2017
VIRTUALREALITYSHOW.CO.UK

ENTER A NEW REALITY

No, someone hasn't slipped an illicit substance into our tea. This is Blortasia – a shape-shifting, virtual reality sculpture park created by Academy Award-winning VFX pioneer Kevin Mack. Designed to stimulate the imagination and awaken the senses, this abstract art world is one of the experiences on offer at the Virtual Reality Show, coming to London in April this year.

Visitors will glimpse the future of this blossoming technology, from video games to fashion, medicine and music. On the Show Stage, 40 experts will showcase the latest VR products and applications, while there'll also be plenty of chance to get hands-on.

Feel the adrenaline rush of free-falling with the skydive simulator, visit a VR military base, step into the shoes of a dementia sufferer, or try out the latest VR games. Just remember to come back to reality...

02

RETHINK GENDER

Boys will be boys and girls will be girls, right? In her new book *Testosterone Rex*, psychologist CORDELIA FINE argues that it's time to scrap gender stereotypes for good

What is Testosterone Rex?

I use this as a nickname for the familiar story that tells us competitive, risk-taking masculinity has evolved for reproductive success, and it's therefore built into male brains and fuelled by testosterone.

I thought Testosterone Rex was a good nickname for two reasons. 'Rex' means king, and this view seems to give an explanation for why men still tend to have more power and wealth than women. And secondly, the set of ideas that Testosterone Rex is based on is now scientifically extinct.

What are the problems with this view?

One problem is that Testosterone Rex is based on an outdated version of evolutionary biology, which assumes that sexual competition is only important for males. This idea came from the observation that reproduction is cheaper for males than it is for females. In humans, for example, the father can supply just a single sperm, while the mother will provide months of gestation, plus labour and breastfeeding. So the risks of competition for status, resources and mates are only worth it for males.

But the economics of reproduction turn out to be much more nuanced than this. Sex roles are diverse and dynamic, and a female's rank and resources can make a big difference to her reproductive success, particularly in mammals.

The Testosterone Rex view also assumes that male and female 'adaptive behaviour' – ways of behaving that would have increased reproductive success in our evolutionary past – is locked into our sex chromosomes and hormones. But even in other species, these adaptations can disappear or even flip between 'masculine' and 'feminine' when something relevant in the environment changes. Consider what this means for humans. We inherit a rich culture with norms, values and expectations that can and do change over time, and the environment in which we develop is completely different to that of our ancestors. Today, we have contraception, equal opportunity legislation, paternity leave and modern technology, all of which have affected our gendered behaviour.

How important is testosterone in shaping gender differences?

When we think, 'men are like this, women are like that', testosterone seems like an obvious explanation since males are exposed to much more of it than females. But male-female differences in 'masculine' traits like risk-taking and promiscuity are much smaller than differences in testosterone levels, so there isn't a simple relationship between testosterone level and masculinity. This fits with what we know about testosterone. The levels in the blood are just one part of a complex hormonal system, and

"The belief that differences between the sexes are large, fixed and biological is not helpful"

testosterone is just one of many factors that feeds into decision-making and behaviour.

What does this all mean for how we think about gender?

The belief that differences between the sexes are large, fixed and deeply biological is not helpful if we're going to have a more balanced society, whether that's more boys playing with dolls, more dads caring for kids, or more women in science and senior leadership roles.

But also, whenever we debate gender equality, in the background is always the idea that natural limits will be set by the fact that males, not females, have evolved to compete for status and resources, and females to care. The science is now showing that the fundamental assumptions behind this are under question – Testosterone Rex is dead, and it's time to find a successor.

TESTOSTERONE REX
BY CORDELIA FINE
OUT 2 MARCH (£14.99, ICON BOOKS).

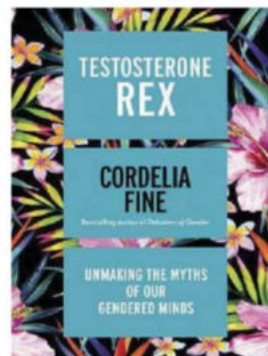


PHOTO: GETTY



03

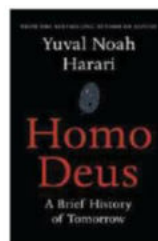
READ OURSELVES HEALTHY

From gothic Victoriana to the future of the human race, the recently announced longlist for the 2017 Wellcome Book Prize is stuffed full of brain food. The 12 fiction and non-fiction books,

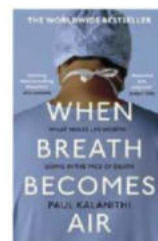
covering themes related to health and medicine, were selected by a judging panel chaired by Scottish crime writer Val McDermid. The winner of the £30,000 prize will be announced on 24 April.



HOW TO SURVIVE A PLAGUE
BY DAVID FRANCE
(PICADOR, NON-FICTION)



HOMO DEUS
BY YUVAL NOAH HARARI
(HARVILL SECKER, NON-FICTION)



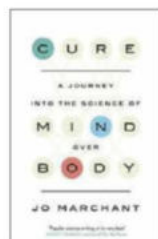
WHEN BREATH BECOMES AIR
BY PAUL KALANITHI
(THE BODLEY HEAD, NON-FICTION)



MEND THE LIVING
BY MAYLIS DE KERANGAL
(MACLEHOSE PRESS, FICTION)



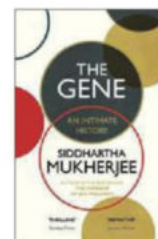
THE GOLDEN AGE
BY JOAN LONDON
(EUROPA EDITIONS, FICTION)



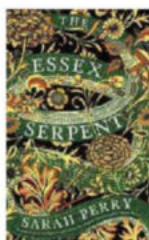
CURE
BY JO MARCHANT
(CANONGATE BOOKS, NON-FICTION)



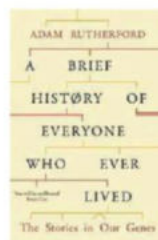
THE TIDAL ZONE
BY SARAH MOSS
(GRANTA BOOKS, FICTION)



THE GENE
BY SIDDHARTHA MUKHERJEE
(THE BODLEY HEAD, NON-FICTION)



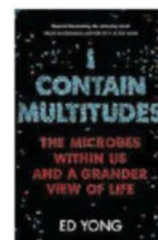
THE ESSEX SERPENT
BY SARAH PERRY
(SERPENT'S TAIL, FICTION)



A BRIEF HISTORY OF EVERYONE WHO EVER LIVED
BY ADAM RUTHERFORD
(WEIDENFELD & NICOLSON, NON-FICTION)



MISS JANE
BY BRAD WATSON
(PICADOR, FICTION)



I CONTAIN MULTITUDES
BY ED YONG
(THE BODLEY HEAD, NON-FICTION)



The word 'perm' comes from the permanent wave hairstyle, which this machine is creating

04

ELECTRICITY: THE SPARK OF LIFE

WELLCOME COLLECTION, LONDON,
UNTIL 25 JUNE 2017, FREE
WELLCOMECOLLECTION.ORG/ELECTRICITY

GET ELECTRICAL

Like fire, meringues and the music of Phil Collins, electricity is one of those things that's familiar and yet strangely beyond description. A new exhibition at the Wellcome Collection tells the story of our quest to understand and harness this all-powerful force. More than 100 objects will be on display, from ancient spark-inducing amber and early electrostatic generators to radiographs, paintings, models and films. There's an early edition of *Frankenstein* (whose author Mary Shelley was inspired by real-life reanimation experiments), a voltaic pile (one of the earliest batteries), surrealist photographs by the artist Man Ray, early examples of neon lighting, and three new commissions from contemporary artists.

While electricity is a life-giver and world-shaper, we often take it for granted. Yet our ability to master it is something of a modern phenomenon.

BOOK NOW

SPACE DESCENT VR WITH TIM PEAKE

JOURNEY FROM THE ISS TO EARTH INSIDE A SOYUZ CAPSULE
SCIENCE MUSEUM, LONDON, FROM 24 MARCH
SCIENCEMUSEUM.ORG.UK/VISITMUSEUM/PLAN_YOUR_VISIT/SIMULATORS/SPACE_DESCENT_VR

05

BRITISH SCIENCE WEEK

10-19 MARCH
BRITISHSCIENCEWEEK.ORG

CELEBRATE BRITISH SCIENCE WEEK

There ain't no party like a science party, and British Science Week returns this March for a 10-day celebration of all things scientific. There are events and activities happening all over the country, from up in the Orkneys to the tip of Cornwall, so there's no excuse not to get involved.

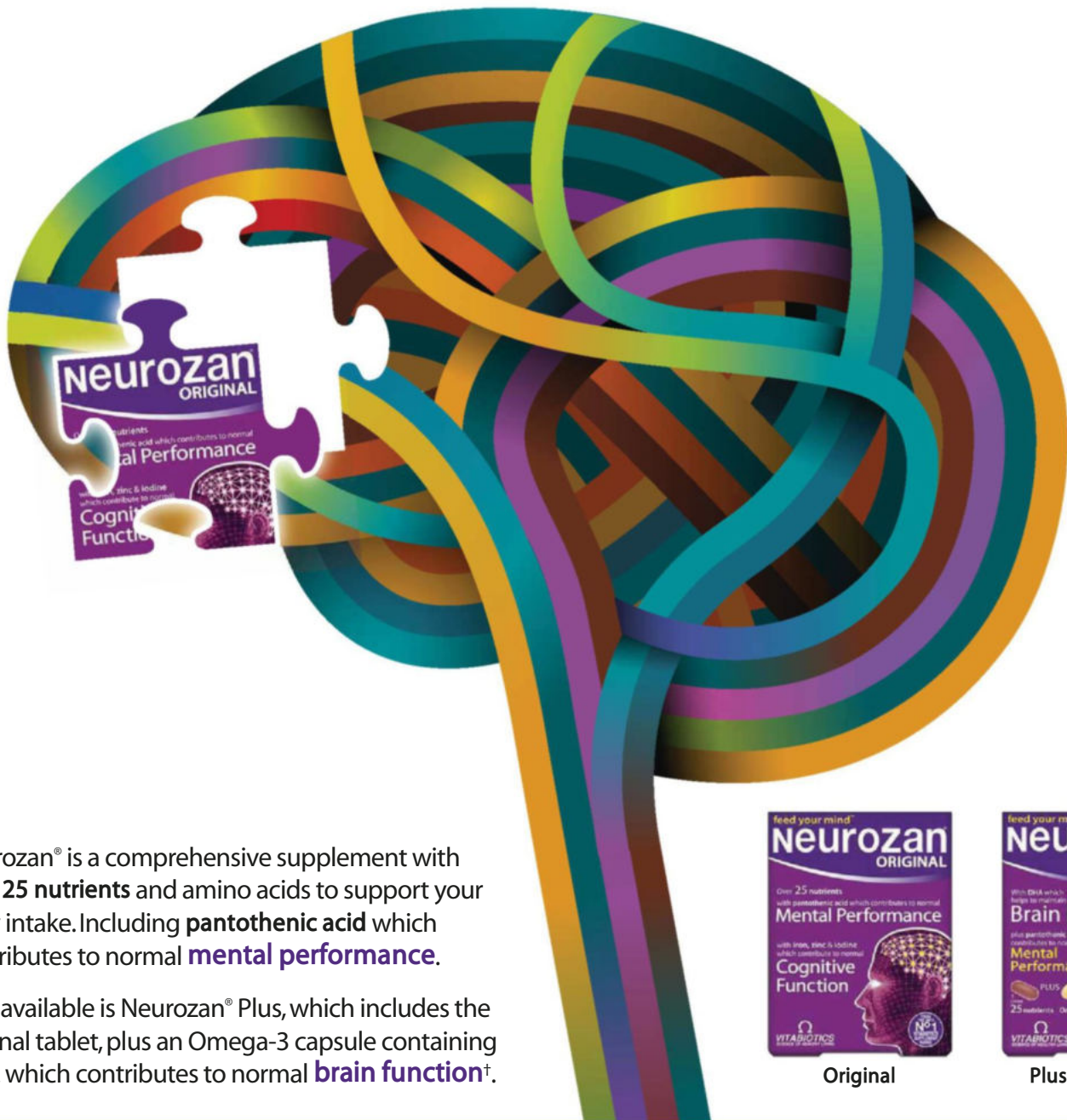
Highlights this year include the *Run The Solar System* running app (see p31); a citizen science project to monitor penguins in the Southern Ocean; a national poster competition; and Demo Day, a campaign to get teachers and pupils involved in hands-on experiments. Browse the events near you at britishscienceweek.org/events



PHOTOS: THE BOARD OF TRUSTEES OF THE SCIENCE MUSEUM, FRAN MOORE

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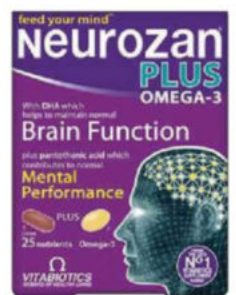


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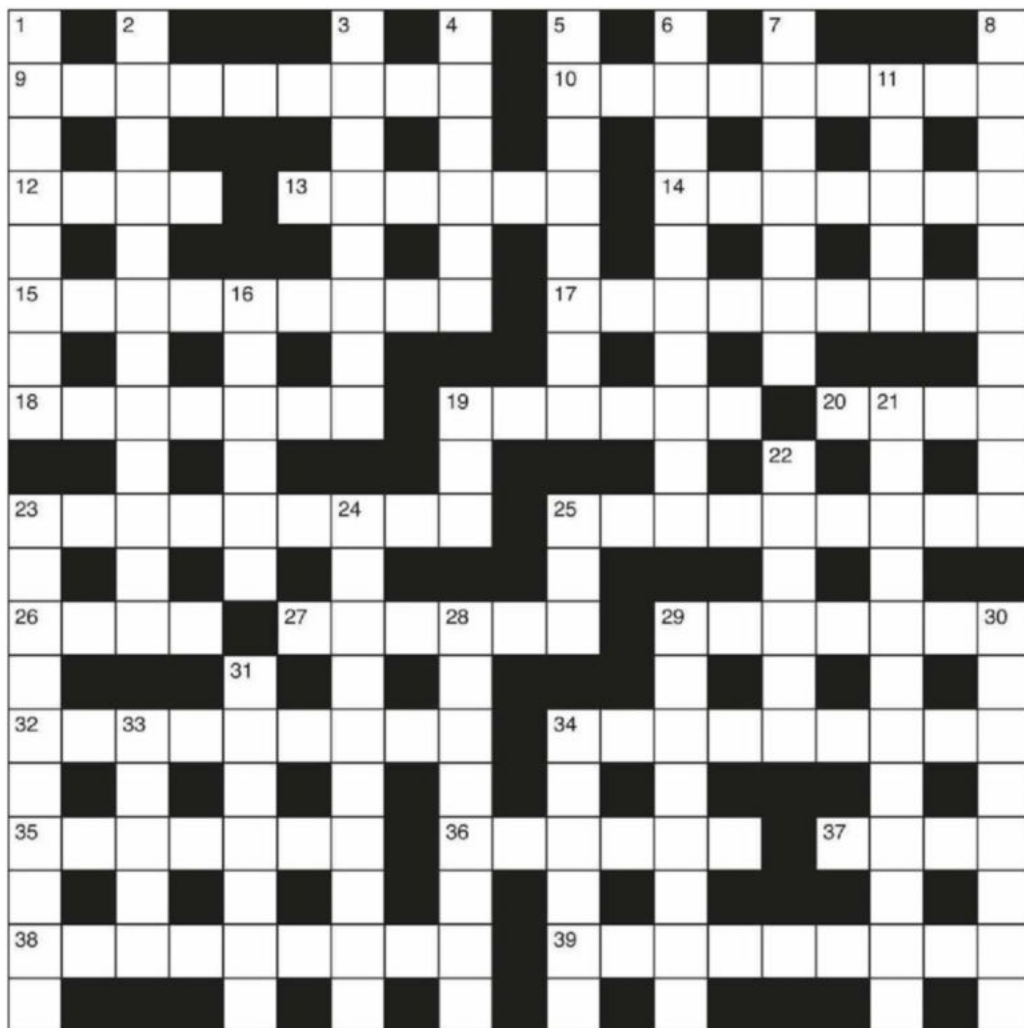


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ACROSS

- 9 Cool cider poured for reptile (9)
 10 Citadel is formed of faith (9)
 12 A graduate has small Syrian garments (4)
 13 Irritate at the plant (6)
 14 German inclination to get American dolphin (7)
 15 Large tome about sensitivity gauge (9)
 17 Unconventional soldier (9)
 18 Search with hesitation for a ship (7)
 19 Set nowadays has a baboon (6)
 20 Organisation drops union to improve appearance (4)
 23 Current supplier gets yet another complaint (5,4)
 25 Lack of oxygen or red blood cells grips bull (9)
 26 Cure using colour (4)
 27 A pungent bulb left out fungus (6)
 29 Hard to get award in identification of primate (7)
 32 Governor is able to captivate woman (9)
 34 Solution is spicier to secondary emergency (9)
 35 Stop getting new tongue (7)
 36 At home, healthy to get some air (6)
 37 Sure to involve employer (4)
 38 Dull girl starts to be a shade military (5,4)
 39 Bankrupt, about to disintegrate (9)

DOWN

- 1 Diver gives old church a tuna recipe (8)
 2 Opposite force on more decorative block of ice (5,7)
 3 Line that crosses British island zone (8)
 4 Not against heater producing variable quantity (6)
 5 Start of Civil War gives advantage to ridge (8)
 6 I did good, playing – with hesitation – an instrument (10)
 7 Odd as a quark (7)
 8 It's cordial, prepared from bacteria (10)
 11 Fuel takes pressure to make resin (5)
 16 Married a peer, getting an illness (6)
 19 Work well together treating leg (3)
 21 Enemy's summit is about defence (6,6)
 22 Field worker constructs frame by river (6)
 23 Ditch a few inches, getting complaint (6,4)
 24 Messenger and swindler have the monkfish (5,5)
 25 Parchment about luminous discharge (3)
 28 Miner managed to break bin to get some money (8)
 29 Lacking cover, like a sphynx (8)
 30 Separate tactful report (8)
 31 Thirty-one days to spread bile about volume (7)
 33 Muslim is a star in reverse (5)
 34 Racial point in moral (6)

ANSWERS

For the answers, visit bit.ly/BBCFocusCW
Please be aware the website address is case-sensitive.

SCIENCE FESTIVAL GUIDE

Your pick of the best science festivals across the UK happening in 2017



ROYAL SOCIETY SUMMER SCIENCE EXHIBITION 4-9 JULY 2017

With 22 fascinating interactive exhibits you can discover the science changing our world. Come along and meet scientists from across the UK and discuss their exciting research, right at the forefront of scientific innovation. From dinosaur forensics, supernovae and your own heart, to quantum computing, mental health and the future of our planet, you can explore cutting edge research from across the sciences. The Summer Science Exhibition is suitable for all ages and features a host of free talks and activities throughout the week.

royalsociety.org/summer / exhibition@royalsociety.org



CHELTENHAM SCIENCE FESTIVAL 6-11 JUNE 2017

A six-day extravaganza with over 200 events celebrating science and the arts, the festival will explore mysteries of the mind, music and sound, our future world and everything in between. Hear from leading experts and entertainers on topics ranging from health and wellbeing, psychology, lifestyle and comedy to tech, the universe, nature and law. Get hands-on in a series of interactive zones and get crafting, building, tinkering and exploring in the MakerShack, a hub of invention and creativity.

cheltenhamfestivals.com / boxoffice@cheltenhamfestivals.com



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imperial.ac.uk / festival@imperial.ac.uk / 020 7594 8198



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pintofscience.co.uk / contact@pintofscience.com

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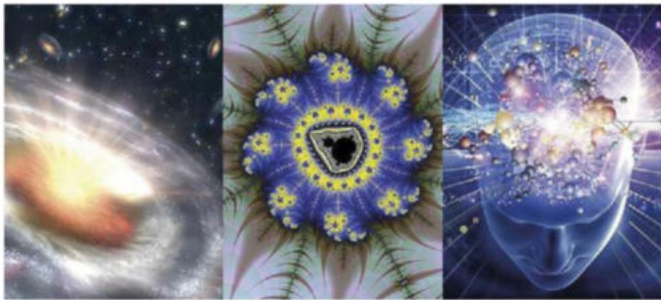
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"I found some cinnabar caterpillars when I was at school. I took them home in my lunchbox"

This month, bee researcher **Prof Dave Goulson** talks to **Helen Pilcher** about the importance of creating a buzz in your back garden

Where does your interest in insects come from?

I think I was born this way. My earliest memories involve butterflies, bees and wildlife generally. I remember finding some stripy cinnabar caterpillars when I was at primary school. I took them home in my lunchbox then reared them on the windowsill in my bedroom. When I was 12, we went on a family holiday to Sweden and saw all these elephant hawkmoth caterpillars crossing the road. They were probably looking for somewhere to burrow and pupate but I spent most of the holiday picking them up and moving them to safety.

How did you come to work on bees?

My PhD was on butterflies, but then I got sidetracked by bees. I was sitting in a local country park watching bees, when I noticed that they don't always land on the flowers they approach. With the help of a PhD student, we worked out why. It turns out the insects are 'sniffing' for previous bee visitors. There's no point landing if the pollen or nectar has already been taken. After that, I was fascinated. Today, I research bee ecology, behaviour and conservation.

How are bees doing these days?

Not great. There are 270 species of bee in the UK, including 26 types of bumblebee and the one and only honeybee, but they're mostly in decline. Habitat loss, disease and the use of pesticides are all to blame. There are seven or eight species of bumblebee that are now very hard to find and overall numbers are diminishing.

And it matters because...?

A third of the food we eat is dependent on insect pollinators. The danger is that bees decline to a point where it affects crop pollination. This is already happening in some places. In parts of China, people have to paint pollen onto fruit trees by hand. Bees are also vitally important for wildflowers.

What can we do to help the bees?

It's not all doom and gloom, there are lots of things we can do to help. Plant bee-friendly flowers like thyme and marjoram. Stop using insecticides and put up bee hotels. These don't need to be expensive; just a bundle of bamboo sticks or a fence post with a few holes drilled in will do. If we could persuade everyone with a garden to do this, it would make a massive difference.

How often do you get stung?

I get stung fairly regularly but thankfully I've not become



allergic to the stings. I have colleagues who have had to give up their work because they developed allergies to bee stings.

Where are you happiest?

In my meadow in France. I have a little farm in the middle of nowhere that I have turned into a nature reserve. Every summer we go for a month and potter about.

Are wasps evil?

No they're not. Wasps are lovely! A lot of people don't realise it but wasps are pollinators too. They are also food for birds and important natural enemies of the pests that feed on our garden plants. 🐝

Prof Dave Goulson is a biologist at the University of Sussex. He founded the Bumblebee Conservation Trust. His new book, *Bee Quest*, is out in April (£16.99, Penguin).

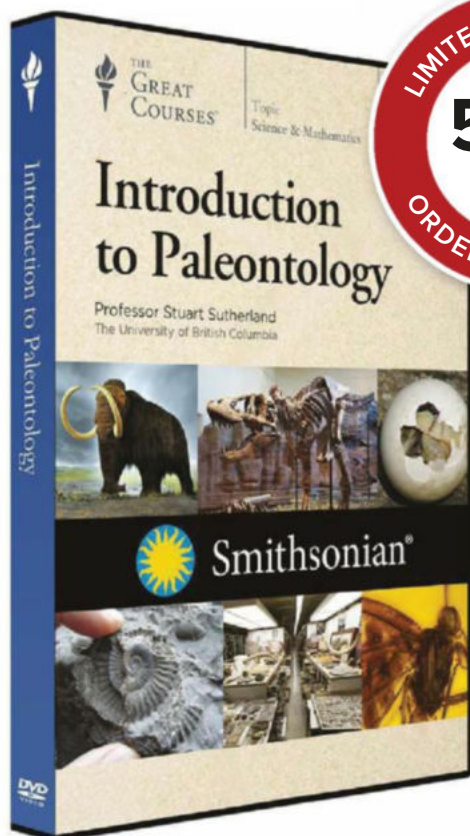
DISCOVER MORE



To listen to an episode of *The Life Scientific* with Dave Goulson,

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NEXT ISSUE: KERRY DAYNES



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Learn how fossils are formed, examine the mass extinctions that have threatened the survival of life on earth, and meet some of the fascinating creatures that are now extinct. Discover the ways in which palaeontology can contribute to some of the challenges faced today by life on Earth and our exploration of other worlds.

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